ANALYSIS OF PAMS DATA IN CALIFORNIA VOLUME III: TRENDS ANALYSES OF CALIFORNIA PAMS AND LONG-TERM TREND AIR QUALITY DATA (1987-1997)

FINAL REPORT
STI-998393-1885-FR

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Prepared for:
U.S. Environmental Protection Agency
Research Triangle Park, NC

May 1999

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PREFACE

In accordance with the 1990 Clean Air Act Amendments, the U.S. Environmental Protection Agency (EPA) initiated the Photochemical Assessment Monitoring Stations (PAMS) program for serious, severe, and extreme ozone nonattainment areas. The PAMS networks monitor for volatile organic compounds (VOCs), ozone, oxides of nitrogen (NO_x), and meteorological parameters. The PAMS networks were designed to provide data for the assessment of population exposure, ozone formation, and evaluation of ozone control strategies. The EPA Office of Air Quality Planning and Standards has sought to provide the EPA regional offices and the states with the necessary analytical tools, training, and guidance to collect and use the PAMS data. To this end, the EPA, California Air Resources Board (ARB), Sacramento Metropolitan Air Quality Management District, San Joaquin Valley Unified Air Pollution Control District, and Ventura County Air Pollution Control District sponsored research into the analysis of PAMS air quality and meteorological data collected at the Districts' PAMS sites in Sacramento, Fresno, and Ventura counties and the ARB's long-term trend sites located in Los Angeles and San Diego. Requested tasks encompass upper-air meteorological data processing and analyses, emission inventory evaluation, and trends analyses. Results of the data analyses for these three topic areas are presented in three volumes:

Analysis of PAMS Data in California Volume I: The use of PAMS radar profiler and RASS data to understand the meteorological processes that influence air quality in selected regions of California. MacDonald C.P., Chinkin L.R., Dye T.S., Anderson C.B. (1999) Report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC by Sonoma Technology, Inc., Petaluma, CA, STI-998391-1888-FR, May.

Analysis of PAMS Data in California Volume II: The use of PAMS data to evaluate regional emission inventories in California. Haste-Funk T.L., Chinkin L.R. (1999) Report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC by Sonoma Technology, Inc., Petaluma, CA, STI-998392-1884-FR, May.

Analysis of PAMS Data in California Volume III: Trends analyses of California PAMS and long-term trend air quality data (1987-1997). Wittig A.E., Main H.H., Roberts P.T., Hurwitt S.H. (1999) Report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC by Sonoma Technology, Inc., Petaluma, CA, STI-998393-1885-FR, May.

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LIST OF ABBREVIATIONS

ARB	California Air Resources Board
CAAA	Clean Air Act Amendment
EPA	U.S. Environmental Protection Agency
EPDC	Expected Peak Day Concentration
GC/FID	Gas chromatography with a flame ionization detector
IR	Interquartile Range
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standard (NAAQS is used interchangeably with 1-hr Ozone NAAQS and 1-hr NAAQS)
NMHC	Non-methane hydrocarbon
NO_x	Nitrogen oxides
NWS	National Weather Service
O_3	Ozone
PAMS	Photochemical Assessment Monitoring Stations
RFG	Reformulated gasoline
RVP	Reid Vapor Pressure
SCAQMD	South Coast Air Quality Management District
SDAPCD	San Diego Air Pollution Control District
SJVUAPCD	San Joaquin Valley Unified Air Pollution Control District
SMAQMD	Sacramento Metropolitan Air Quality Management District
STI	Sonoma Technology, Inc.
T	Temperature
T850	Temperature at 850 millibars

T_{dp}	Dew point temperature
VCAPCD	Ventura County Air Pollution Control District
VMT	Vehicle miles traveled
VOC	Volatile Organic Compound
WD	Wind direction
WS	Wind speed

1. INTRODUCTION

1.1 OBJECTIVES

This work evaluates long-term changes in air quality in selected Metropolitan Statistical Areas (MSAs) in California. The analyses are intended to assist local, state, and federal air quality agencies to evaluate the effectiveness of their emissions control programs, and evaluate the progress toward lowering public health risks and attainment of the National Ambient Air Quality Standards (NAAQS) and the California Ozone Standards. The task of evaluating an emission control program is not trivial, and the conclusions of the analyses are often confounded by the complex relationship between emissions controls, population growth, local and regional meteorology, and ambient air quality. The use of multiple approaches (or analyses) to investigate long-term changes in air quality is used in this work to gain insight into the effectiveness of emissions control strategies. The findings of these analyses can assist regions in the redevelopment of their air pollution abatement strategies. The current analyses seek to respond to two questions:

- Is ozone air quality in California improving?
- Are the improvements in the ozone air quality likely to be in response to the implemented emissions control programs?

The responses to these questions are based on analyses conducted at selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego and Ventura Metropolitan Statistical Areas. Most of these sites have been designated Photochemical Assessment Monitoring Station (PAMS) sites, and are associated with extensive speciated volatile organic compound (VOC) measurements. These measurements have allowed researchers to improve their current understanding of the complex photochemistry of air pollution, in terms of the relationship between ozone precursors, such as VOCs and nitrogen oxides (NO_x), and observed pollutant concentrations. PAMS measurements have also allowed researchers to identify air quality issues on a regional scale and to track the effectiveness of emissions control programs by following particular chemicals in relation to particular source reductions (such as reductions as a result of the introduction of reformulated gasoline). With PAMS measurements researchers can evaluate the effectiveness of a particular VOC reduction in a particular air shed.

The PAMS sites have been selected to help researchers better understand the effect of precursors and photochemistry on pollutant formation. There are four classifications of PAMS sites. These classifications identify the relevance of the site to pollutant formation:

- Type 1: upwind and background site
- Type 2: maximum ozone precursor emissions site
- Type 3: maximum ozone concentration site
- Type 4: extreme downwind monitoring site

Type 1 sites are intended to capture background concentrations of pollutants that may or may not contain pollutants from upwind locations. The influences of fresh emissions sources are assumed to be minimal at this type of site. Type 2 sites are typically located in the center of an urban area where the emission strengths are the greatest. As a result of the nearby fresh emissions sources, these sites are intended to capture maximum ozone precursor concentrations. Type 3 sites are intended to capture the highest ozone concentrations. These sites are typically in areas that are downwind of urban centers and their associated ozone precursor (emissions) sources. In the time it takes for the ozone precursors to travel from their point of emission to this downwind area, they are expected to have reacted in the presence of sunlight to produce ozone. Type 4 sites are intended to capture the concentrations of pollutants as they are transported from the MSA. The ozone concentrations decrease from their maximum concentrations due to a lack of fresh emissions sources, and as a result of photochemical reactions and losses with the surface. The California Air Resources Board (ARB) also maintains several PAMS sites for their long-term trends analyses.

In this work, multiple approaches to long-term trends were considered to address the two questions listed previously. Multiple approaches are essential because individual trend analyses are often limited by uncertainties in the measurements, and/or the unavailability of critical measurements. Because the relationship between emissions controls, population growth, meteorology and ozone air quality is complex, true trends are difficult to establish using any method. When measurement issues such as missing years of measurements or differences in reporting units are also considered, trends can be less conclusive or misleading. No one indicator (especially in terms of meteorological adjustment) has been found to be robust enough to diminish the cyclic trends seen in ozone measurements for every type of site; this is why there are numerous approaches to this task and the work is ongoing. However, the use of collaborative trend analyses involving some of the meteorological adjustment techniques can be used to suggest when one method is not robust enough or applicable for a particular site. Therefore, no single analysis should be used to determine responses to these two questions. Instead, collaborative trend analyses should be considered in order to confirm the trends of any single analysis. This approach was taken for this work. The specific objectives of this project include the following:

- Conduct trends analyses using valid measurements from selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs, using ozone and ozone precursor concentrations as trend indicators.
- Evaluate and recommend measurement analysis methods for the adjustment and removal of meteorological influences on the ozone trend indicators.
- Compare the precursor trends and the expected peak day concentrations (EPDCs) of ozone for the Type 2 PAMS sites.
- Perform a statistical evaluation of the sampling frequency required to detect actual and expected trends in various parameters.

Several approaches to trends analyses were identified from a literature review of previous and current work. These approaches differ in their measurement requirements and numerical intensity; measurement availability was found to dictate which approaches could be considered for this work. Even the simpler approaches require considerable amounts of air quality measurements (e.g., at least three continuous years of valid ozone exceedance concentrations). The more complex approaches often had greater measurement requirements (e.g., at least three continuous years of valid daily maximum ozone concentrations, concurrent precursor measurements, and/or concurrent meteorological measurements). The gaps in the meteorological measurements were supplemented with nearby measurements, when they were available, to enable more complete analyses to be performed.

As a result of the literature review and an assessment of measurement availability, the ozone trends were investigated in the context of exceedances of the 1-hr Federal and State ozone standards, and concurrent NO_x and VOC precursor measurements. However, ozone trends analyses are often complicated by variations in meteorological conditions. These year-to-year variations tend to obscure the underlying trends in ozone changes as a result of emissions reductions or increases. Therefore, the influence of meteorology on the trends was also considered. Detailed trends analyses were conducted at selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs. These sites are described in **Table 1-1.**

The United States Environmental Protection Agency (EPA), the ARB, and several local districts including the Sacramento Metropolitan Air Quality Management District (SMAQMD), the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD), and the Ventura County Air Pollution Control District (VCAPCD) jointly sponsored this work. Associated reports on VOC measurements (Main et al., 1999), upper-air meteorological measurements (MacDonald et al., 1999), and emission inventory evaluation (Haste and Chinkin, 1999) were produced from analyses performed at similar selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura Metropolitan Statistical Areas.

1.2 ORGANIZATION OF THIS REPORT

The remainder of this report is broken into ten technical sections. Section 2 presents necessary background information, focusing on the issues that often limit trends analyses. This section begins with a discussion of the uncertainties in the collected measurements and continues with a discussion of the availability of measurements at the sites listed in Table 1-1. This section is concluded with a description of the trend indicators and statistics that will be applied to the available measurements. In Section 3, ozone exceedance trends, correlation with precursors, and correlation with meteorology are addressed. Methods that are beyond the scope of this work are also compared and contrasted. Sections 3 through 8 present the findings of the trends analyses for each of the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs. Each of these sections focus on a single MSA, and include a summary of trends for each MSA, detailed analyses of the PAMS Type 2 and ARB sites, and specific examples of the issues (uncertainties) discussed in Section 2 that limit the analyses.

The VOC trends analyses are presented in Section 9. Conclusions and recommendations are presented in Section 10 of the report. References are provided in Section 11. Appendices A through G provide supplemental information. Appendix A provides correlation plots for the supplemental temperature measurements. Appendices B, C, D, E, F, and G focus on a single MSA and provide statistical analyses for the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura sites that are not discussed explicitly in the report.

Table 1-1. Description of MSA sites.

AIRS ID	Site Name	MSA	Site Type [a]	Latitude	Longitude
060670011	Elk-Grove Bruceville	Sacramento	1	38.303	-121.4207
060670006	Del Paso Manor	Sacramento	2	38.614	-121.3669
060671001	Folsom	Sacramento	3	38.675	-121.1858
060670012	New Folsom	Sacramento	3	38.684	-121.1628
060290010	Golden State Avenue	Bakersfield	2	35.385	-119.0147
060295001	Arvin	Bakersfield	1 and 3	35.209	-118.7763
060195001	Clovis-Villa	Fresno	2	36.819	-119.7166
060190008	Fresno 1st Street	Fresno	ARB	36.782	-119.7732
060194001	Parlier	Fresno	3	36.597	-119.5042
060731007	San Diego 12th Street	San Diego	ARB	32.710	-117.1526
060371103	Los Angeles North Main	Los Angeles	ARB	34.067	-118.242
061112003	Emma Wood Beach	Ventura	1	32.280	-119.3153
061113001	El Rio	Ventura	2	34.252	-119.1545
061112002	Simi Valley	Ventura	3	34.278	-118.6847

[a] Type 1: upwind and background site, Type 2: maximum ozone precursor emissions site, Type 3: maximum ozone concentration site.

2. BACKGROUND AND TECHNICAL APPROACH

This section presents some of the issues that complicate air quality analyses and the resultant technical approach that will be taken in this work as a result of these issues. Two primary issues are:

- Uncertainties as a result of atmospheric variability, meteorological variability, measurement techniques, and analysis techniques.
- Availability of complete, continuous measurements.

Each issue has a different impact on the analyses. The uncertainties that are a result of these issues affect the ability to interpret the results of the analyses. The availability of complete, continuous measurements dictates what analyses can be performed.

This section focuses on the background information necessary to develop the technical approach that was employed in this work, and is organized into three subsections. A detailed discussion of the issues that impact the ability to discern clear trends by introducing uncertainty into the analyses is presented in Section 2.1. The availability of measurements, which will determined what analyses could be performed in this work, is discussed in Section 2.2. The conceptual strategy, goals, and measurement needs of the analyses that were considered are discussed in Section 2.3. Together, the uncertainties and the availability of complete and continuous measurements were the deciding factors as to which analyses would be performed within the budget and scope of this work. Many analyses are considered and discussed in Section 2.3, but the availability of measurements, the numerical intensity of a particular analysis, or the applicability of an analysis technique determined which analyses were actually performed. The first set of analyses discussed in Section 2.3 were conducted using the measurements that were made available to Sonoma Technology, Inc. (STI) by the ARB (California Air Resources Board, 1997). The second set of analyses was performed by other researchers for selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs. These results are presented and the findings are analyzed in the context of the uncertainties (discussed in Section 2.1) and the results of the analyses performed by STI. The third set of analyses was either beyond the scope of this work due to their numerical intensity and measurement requirements or was not expected to yield constructive results because of questionable assumptions. This last set of analyses is discussed in Sections 2.3.3 and 2.3.6 for comparison purposes only.

2.1 UNCERTAINTIES

Uncertainties impact the ability to clearly discern air quality trends in an analysis. Uncertainties place confidence limits on the parameters that are being analyzed and should be used to caveat upward or downward trends in the measurements that are actually within the variability or uncertainty of the measurement. Some uncertainties that affect the trends developed in this work are:

1. Atmospheric variability associated with short-term fluctuations in meteorological conditions and source emissions.
2. Meteorological variability associated with synoptic seasonal cycles.
3. Measurement uncertainty associated with instrument accuracy and precision.
4. Analysis uncertainty associated with trend indicator interpretation.

The first two uncertainties are the a result of real atmospheric events and can impact long-term trending by introducing real variability into the measurements. Short-term atmospheric variability can be the result of meteorological or emission events that are uncommon (anomalous events) and result in measurements that are inconsistent from one day to the next. Meteorological variability is considered a result of changes in seasonal cycles. This type of uncertainty normally occurs on a longer time scale and is a result of changes in the measurements due to seasonal changes in meteorology. Both of these variabilities are the result of real atmospheric events and cause real uncertainties in the measurements. (This is contrary to the uncertainties that are a result of measurement and analysis techniques; these uncertainties are the result of a statistical uncertainty or artifact.) Many researchers have dedicated their time to developing methods to account for or adjust for these variations. For example, Larsen uses native variability and expected peak day concentrations to account for the effects of uncommon short-term atmospheric meteorological or emission fluctuations (e.g., California Air Resources Board, 1993). Cox and Chu adjust ozone measurements to account for seasonal differences from year-to-year (e.g., Cox and Chu, 1993). Rao and Zurbenko adjust ozone measurements to account for differences from year-to-year in both atmospheric fluctuations and seasonal meteorology (e.g., Rao and Zurbenko, 1994). These and other methods will be discussed in detail later in Section 2.3.

Measurement uncertainties are the result of limitations in the equipment used to collect the measurements and are dictated by the accuracy and precision of the instrument. The accuracy of the instrument is limited by its construction and measurement technique, while the precision of the instrument is limited by its performance over time. In this work, we have assumed that the measurements reported to STI by the ARB are without accuracy issues. This assumes that the instruments were maintained according to routine procedures that insure that the accuracy of the instrument has not changed over time. However, precision limitations on the measurements can be a major issue for trend analyses. Typically, the instruments are calibrated on a quarterly basis in the field and routine checks of the calibration are used to determine the precision of the instrument between calibrations. For example, the instrument is calibrated every four months to be accurate over a range from 0 to 150 ppb ozone. On a daily basis, the instrument is challenged with 150 ppb of ozone from a known source of ozone and reports its measurement of this known source of ozone. The standard deviation of the reported measurements of the known source of 150 ppb ozone over the 4-month period represents the precision of the instrument.

Measurement precision is not only an issue for ozone instruments. Commonly used NO_x and temperature instruments also have measurement uncertainties as a result of instrument precision limitations that are on the order of a fraction of the measured concentration.

Hydrocarbon measurement instruments, such as a GC/FID (gas chromatography with flame ionization detection), typically have an uncertainty of approximately 10 to 20 percent of the total nonmethane hydrocarbon (NMHC) and individual hydrocarbon measurements; this uncertainty range is based on audits of the GC/FID. Typically, these instruments have minimum detection limits of 0.2 to 1 ppbC for the individual PAMS hydrocarbons, and 50 ppbC for the total NMHC. Some commonly observed measurement precisions are shown in **Table 2-1**.

Analysis uncertainties are the result of compiling large amounts of measurements into a single performance indicator, such as the average exceedance concentration for ozone. When the measurements are further processed, uncertainties due to instrument precision are compounded beyond the original instrument precision limitations. The standard deviation of the processed concentrations is considered to represent the analysis uncertainty. For a typical trend analysis, several averages of the original measurements are computed. To minimize the analysis uncertainty on the computed averages, smaller subsets of the entire measurement set that are more consistent (e.g., morning concentrations) or better characterize the issue (exceedance concentrations) are used in the computations. This selection of the measurements prior to averaging allows for more robust average concentrations to be calculated (as indicated by smaller analysis uncertainties). When the averages are more robust, they can be considered to be more representative of the entire body of measurements and a better indicator of trends in air quality at the site. Typical averages that were computed for this work include:

- Hourly average concentrations are averaged to obtain 3-hr average concentrations (e.g., NO_x).
- Daily maximum concentrations are averaged to obtain annual average maximum concentrations.
- Annual average maximum concentrations are averaged to obtain running 3-yr average maximum concentrations.

The standard deviation of the average concentration from the range of concentrations in the measurement set was used to determine the analysis uncertainty in this work. These uncertainties are associated with and used to caveat the trends in this work because the analysis uncertainty was normally larger than the measurement uncertainty.

The overall ability to discern clear trends is limited by the largest uncertainty or variability of the four listed previously. Two questions that arise as a result of this point are:

1) How should these uncertainties be prioritized?
2) How will the prioritization of these uncertainties impact the analyses?

The inability to discern clear trends is commonly assumed to be a result of atmospheric and meteorological variabilities. Typically, the uncertainties due to measurements and analysis artifacts are assumed to be much smaller than the uncertainties in the measurements due to atmospheric and meteorological variability. As a result, measurement and analysis

uncertainties are commonly ignored even though their relative importance might be great, and trends established during an analysis are only interpreted in the context of atmospheric and meteorological variabilities. Routine statistical analyses are typically interpreted with an a priori knowledge of anomalous meteorological events. When resources and measurements are available, more numerically or measurement intensive techniques such as those proposed by Larsen, Cox and Chu, and Rao and Zurbenko are used to identify the amount of the trend that is attributable to meteorology. However, because these techniques use the same original measurement set as the routine analyses, they are subject to similar measurement and analysis uncertainties, and their trends do not solely investigate the uncertainty in the measurements as a function of atmospheric and/or meteorological variability.

In actuality, measurement and analysis uncertainties will partially impair the analyses at every site. However, the importance of these uncertainties relative to atmospheric and meteorological variability is dependent on the particular site. In some instances, the relative prioritization of the issues will change as differences in pollutant concentrations from one year to the next approach the uncertainty of the measurement or the analysis. To account for these uncertainties, both routine statistical analyses and analyses that are supposed to address the influence of atmospheric and meteorological variability on the trends were proposed to be critically evaluated in this work. Measurement and analysis uncertainties are used to caveat the findings.

2.2 MEASUREMENT AVAILABILITY

The previous section of the report discussed several uncertainties that are believed to impact one's ability to clearly discern air quality trends in an analysis and will affect the way that the trends will be interpreted. This section of the report focuses on measurement availability. Poor measurement availability can impact trend analyses in the following two ways:

1. By limiting the ability to determine if the body of measurements is representative of the air quality experienced at the site. When air quality measurements have poor availability, it is unknown whether all possible atmospheric and meteorological variability has been captured within the measurements. Therefore, it is unknown whether the measurements fully represent the air quality at a particular site. This is of particular issue when high ozone concentration days are not represented in the measurements, considering that these days are the most important from a public health standpoint. Under these conditions, the trends that are developed in the analyses do not take into account all possible events that lead to high ozone concentrations and are biased accordingly.

2. By limiting the types of analyses that can be performed. When measurements are not available for analyses that require them, the analyses can clearly not be performed. Therefore, the number of approaches that can be taken to develop trends in the air quality at a particular site are limited to the number of approaches that only use the measurements that are available.

Measurement availability is typically limited by the continuity and span of individual measurements that should be included in trends analyses or by the continuity of the entire measurement set when the singular measurements are considered together. These issues were investigated during the review of the ozone (O_3), NO_x, VOCs, and meteorological measurements that were made available to STI by the ARB. The results of the measurement completeness investigations are presented in **Table 2-2**.

2.2.1 Individual measurements (O_3, NO_x, VOC, meteorology)

Measurement completeness

Reasonable measurement completeness is used to demonstrate that the validated measurement set statistically represents the air quality at a particular site. The measurement completeness criteria that were employed in this work are as follows:

- At least 75 percent of the measurements were available from 9 a.m. to 9 p.m.
- Approximately 75 percent of the measurements were available from May through October.
- Approximately 75 percent of the measurements were available annually.

To maximize the measurement usage, the criteria were allowed to be less rigorous than criteria that are typically used in air quality analyses performed by the ARB because only partial years of measurements were available in several cases. Incomplete measurements on a daytime basis were automatically excluded from the analysis. This criterion was employed to be certain that the full diurnal pattern of ozone concentrations was considered and the maximum concentration was captured. Because high concentrations of tropospheric ozone are formed as a result of photolysis reactions, the maximum ozone concentration will typically occur during daytime hours. Incomplete monthly measurements and incomplete annual measurements were not automatically excluded from the analyses. These last two criteria were not strictly enforced because compliance with the criteria would have severely limited trends from being developed. Meteorological conditions during the summer months tend to be more conducive to ozone formation. Therefore, incomplete monthly measurements were only considered acceptable if 75 percent of each of the summer months were accounted for. However, all of the measurements that were included in the analyses despite obvious limitations were noted in Table 2-1 to caution the user from over-interpreting overall trends based on the specific years of concern.

Availability of individual measurements over a continuous time frame

Single years of measurements can be shown to statistically represent the air quality at a particular site by following the guidelines established in the previous section. However, the ability to develop temporal trends is based on the availability of continuous measurements that span at least three years. Therefore, the availability of ozone, NO_x, VOC, and meteorological measurements over a continuous time frame was also investigated. A minimum span of ten

years is desired to discern long-term trends in any measurement. However, for this work, the time span of available valid ozone measurements was used to determine the minimum time span over which analyses would be performed. A minimum span of four years was considered to be acceptable for this work to include all sites. The availability of meteorological measurements (besides temperature) was found to be far more limited. While wind speed, wind direction, solar radiation and relative humidity measurements have been used to reveal different insights in ozone-precursor relationships, four valid and continuous years of these meteorological measurements were not available at any of the sites.

Other discontinuities in measurements

Even if a continuous span of at least four years of valid measurements were available at each site, there were other discontinuities in the measurements that may limit the ability to discern long-term trends in the measurements, including:

- Differences in reporting units (i.e., pphm O_3 vs. ppb O_3) and
- Spatial relocation of monitoring sites

One example of this discontinuity was the difference in significant figures associated with the reported ozone measurements. For a majority of the sites, an additional significant figure was associated with the ozone measurements in years including and following 1994. Some sites experienced this transition even earlier (e.g., Del Paso Manor, San Diego 12th Street, Emma Wood Beach, El Rio and Simi Valley). The result of the transition in significant figures is that the measurements and therefore trends are not all on the same basis.

Another example of measurement discontinuity was observed at the Folsom site. This site was physically relocated on September 1, 1996, during the ozone season when the highest ozone concentrations are typically measured. The result of this site relocation is a potential discontinuity in the measurements and trends. The previous site was located near a roadway where ozone was titrated by fresh automobile emissions of NO. The new Folsom location was chosen to decrease this bias, so that the measurements would be representative of the highest ozone concentrations in the Folsom area. However, this means that the measurements at the new site should be different than the measurements at the former site. Long-term trending at this site will probably be influenced by this change.

2.2.2 Continuity of the entire measurement set (O_3, NO_x, VOC, and meteorology)

Availability of multiple measurements

Correlations between any of the continuous valid measurements (such as average ozone exceedance concentration to average ambient temperature) require collocated measurements that span identical time periods. Long-term trending of the continuous valid measurements will be limited when multiple measurements are not available over the same time periods because analyses cannot be performed using missing measurements. Therefore, the continuity

of the current measurement set was investigated by considering the availability of multiple measurements at a single site over a continuous time frame.

When the continuity of the measurement sets was investigated, concurrent temperature and ozone measurements showed deficiencies. In order to be able to analyze the ozone measurements in the context of concurrent temperature measurements, the available temperature measurements were supplemented with measurements made at nearby National Weather Service (NWS) stations. Correlation techniques were used to demonstrate a reasonable correlation between the selected sites and the nearby NWS stations. The NWS data showed excellent correlation with the temperature measurements made at the PAMS or long-term trend sites. **Figure 2-1** illustrates the relative positioning of the Los Angeles North Main Street site and the Los Angeles Airport NWS station. **Figure 2-2** shows a comparison of the temperature measurements that were collected concurrently at both the sites. The relationship between the two temperature measurements was:

$$\text{Temperature (Civic Center)} = 0.6434 \times \text{Temperature (LAX Airport)} + 22.824;\ R^2 = 0.7983$$

Excellent correlation was also demonstrated at the Del Paso Manor, Arvin, Clovis, and Fresno sites; the figures that demonstrate the correlation of the available temperature measurements at the selected PAMS sites and the NWS sites are presented in Appendix A. At these sites, a more complete set of measurements was developed by supplementing missing temperature measurements at the Del Paso Manor, Arvin, Clovis, Fresno, and Los Angeles sites with NWS data from nearby airports. Temperature measurements at the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs were sporadic from 1990 to 1994. Therefore, NWS temperature measurements up to 1995 were consistently used to supplement the ARB temperature data set.

When the continuity of the measurement sets was investigated for 1990 to 1997, concurrent precursor and ozone measurements showed deficiencies. The analyses that compared ambient NO_x precursor concentrations were limited by the availability of VOC measurements. While NO_x measurements were made on a continuous basis, speciated VOC measurements were only collected every third day at most sites. Therefore, only a subset of available NO_x measurements was used in analyses that involved concurrent VOC measurements. Supplemental continuous NO_x and speciated VOC measurements were not available. The continuous NMHC measurement data set was not considered as it was not fully validated for this project (see Main et al., 1999). In addition, complete NO_x, VOC, and temperature measurements were not concurrently available over the same time periods for which complete ozone measurements were available. A list of the years and sources of the supplemented NWS temperature measurements is presented in **Table 2-3**. The analyses presented in the following sections of the report feature these measurements.

2.3 DISCUSSION OF TRENDS INVESTIGATED IN THIS PROJECT

The impact of several issues on the ability to discern clear trends in air quality analyses was discussed in Section 2.1. This discussion led to an awareness of the relative importance of the issues and a decision to evaluate the variability using several tools when the appropriate measurement were available, and the need to caveat all of the analyses with instrument precision and measurement uncertainties. The availability of continuous collocated validated measurements of ozone, NO_x, VOC and temperature was discussed in Section 2.2. This discussion led to an understanding of the types of measurements that are available for use in the current analyses, and an expansion of the available information (and the analyses that could be performed) using correlated temperature measurements made at nearby airports. In this section of the report, the trend analyses performed in this work are introduced. These analyses use the supplemental measurements described in Section 2.2 and consider the issues discussed in Section 2.1 to place confidence limits on any trends that are developed.

This section presents and discusses the analysis techniques that were considered in this work. These techniques can be broken into the following categories:

- Statistical and adjustment techniques employed in this work.
- Statistical and adjustment techniques already applied to California measurements.
- Statistical and adjustment techniques not employed in this work.

The statistical techniques involve the use of statistics on the raw measurements to discern trends. The adjustment techniques involve some processing of the ozone measurements to remove the influence of particular events or conditions from the data prior to any trends analyses. The statistical and adjustment techniques employed in this work and by others are discussed in detail in this section, and the results of the analyses are evaluated in Section 3. Several analysis techniques were not considered for the current work because the measurement needs of the analyses could not be met, the numerical intensity of the analyses was beyond the scope of this work, or questionable assumptions were associated with the analyses; these are discussed in this section as well. Finally, the adjustment techniques are compared at the end of this section so that an analyst could decide which methods are the most reasonable to consider when more consecutive years of meteorological measurements become available.

2.3.1 Statistical techniques employed in this report

The statistical techniques involve the use of statistics on the raw measurements to discern trends. Many indicators were developed using these statistics to obtain insight into the air quality issues at the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs.

In this work, statistics were computed based on compliance with both the 1-hr Ozone NAAQS and California Ozone Standard; air quality monitoring sites in California are subject

to both of the standards. These standards are used to protect human health by gauging the air quality in the region surrounding the site (see **Table 2-4**).

Most PAMS sites report ozone concentrations in ppb units. In terms of ppb units, a 1-hr average concentration of 124 ppb is considered to be in compliance with the 1-hr Ozone NAAQS (i.e., the concentration is rounded to 0.12 ppm). Similarly, a 1-hr concentration of 94 ppb is considered to be in compliance with the California Ozone Standard (i.e., the concentration is rounded to 0.09 ppm).

The transition to the 8-hr NAAQS for ozone is just beginning. However, when this work was begun, the 1-hr NAAQS was of most interest; therefore, the 1-hr NAAQS was the focus of this work. For some of the sites considered in this analysis, the air quality (in terms of ozone) is better than at others, and compliance with the 1-hr NAAQS is not as much of an issue as compliance with the California Ozone Standard (e.g., Elk Grove - Bruceville site in the Sacramento MSA). For other sites, compliance with the 1-hr Ozone NAAQS is still very much an issue (e.g.. the Folsom site in the Sacramento MSA). Therefore, in this report, exceedances of both the NAAQS and California 1-hr ozone standards were considered in the trend analyses.

The following statistical indicators were prepared and investigated in this work:

- The total number of exceedances of the standard within a single year indicates by how much the site is violating the 1-hr NAAQS and the California Ozone Standard. These standards only allow for a single violation within a single year.
- The average exceedance concentration was determined for each year at each site. This statistic is used to indicate the average air quality on days when the air was considered to be poor according to the 1-hr Ozone NAAQS and the California Ozone Standard. The average exceedance concentrations were determined separately for each of the two standards.
- A running 3-yr average of the average exceedance concentration was used to reduce the dramatic effects that anomalous air quality episodes can have on the overall trends at the site. A 3-yr running average should not substantially bias the trends at sites that do not experience upward and downward variations from year to year. However, for sites that do not exceed the 1-hr Ozone NAAQS and the California Ozone Standard each year, this analysis can become complicated. A moving average requires non-zero concentrations for each year of the analysis, but it is inconsistent to use invalidated exceedance concentrations or valid non-exceedance concentrations. In this work, valid non-exceedance concentrations were used so that the analyses could be performed; these cases were noted.
- By identifying the top three exceedances (i.e., Rank 1, Rank 2, and Rank 3), it is possible to gain insight into the nature of the average exceedance concentration. This statistic can be used to indicate whether a single anomalous exceedance brought the site out of compliance, or if the highest exceedance concentrations are representative of commonly experienced elevated ozone concentrations.

- The number of exceedances above selected thresholds can also be used to gain insight into the nature of the average exceedance concentration. This statistic lends a different perspective than the ranking of the top three exceedance concentrations when a site experiences more than three exceedances within a single year (as is the case for many of the sites considered in this work). Like the ranking statistic, the identification of exceedance thresholds gives a sense of whether or not the highest exceedance concentrations are anomalies or are representative of commonly experienced elevated ozone concentrations. Thresholds selected for this analysis included:
    - 0.09 ppm O_3 (for compliance with California Ozone Standard only)
    - 0.12 ppm O_3 (for compliance with 1-hr Ozone NAAQS)
    - 0.14 ppm O_3
    - 0.16 ppm O_3
    - 0.18 ppm O_3

- A classification of the number of exceedances by day of week can be used to gain more insight into the nature of the exceedances. When exceedances follow weekly patterns, it is likely that the emissions that also occur on a weekly basis (e.g., motor vehicle emissions) contributed to the exceedances.
- A classification of the number of exceedances under selected meteorological conditions was also used. It has been well established that elevated ozone concentrations can be the result of changes in emissions and meteorology. However, it is difficult to distinguish between ozone formed due to emissions changes, the ozone formed due to transport from upwind area, and the ozone formed due to conducive local ambient conditions. By mapping the spatial distribution of the exceedances, insight into regional transport issues can be inferred. This statistic is useful because regional transport of pollutants from upwind sites to downwind sites has been demonstrated to have dramatic effects on the air quality at a downwind site that does not normally have problems complying with either of the 1-hr ozone standards (e.g., Main et al., 1997). Maximum annual average temperature and maximum annual temperatures over 90°F can be used to gain insight into the relationship between local meteorology and elevated ozone concentrations at a particular site. In general, ozone standard exceedances are associated with higher daily maximum temperatures as emissions into the region are decreased.
- An analysis of the expected peak day concentrations (EPDCs) as a function of early morning precursor concentrations can be used to gain insight into the effects of the emissions on the observed ozone concentrations. The analysis was performed for the PAMS type 2 sites where precursor emissions were anticipated to be the greatest, as well as for several ARB sites. The analysis compares the EPDCs to the observed second highest annual exceedance concentration and investigates the relationship of these exceedance concentrations to the ratio of the early morning precursor concentrations.

Both VOCs and NO_x participate in complex photochemical reactions to produce tropospheric ozone. However, a simple ratio of early morning VOC-to-NO_x measurements can be used to approximately identify whether VOCs or NO_x in the ambient air (or both) limit the overall formation of ozone. This insight can be gained despite the complexity of the photochemistry because certain ratios of the early morning VOC and NO_x concentrations have been observed to result in reductions or increases in the amount of ozone formed over the course of a day (National Research Council, 1991) as listed in **Table 2-5**.

These ratios are based on ozone isopleth plots that illustrate the changes in measured ozone as a function of early morning ambient VOC and NO_x measurements. Because it is expected that the early morning precursor concentrations will be greatest at locations where the precursor emissions are the greatest, this statistic will only be determined for the PAMS Type 2 sites where precursor emissions are assumed to be maximum, and some PAMS Type 2-like ARB sites.

Because the EPDC is a hypothetical concentration, it is also interesting to compare the EPDC to the highest ozone concentrations that were observed at the site, to assess the applicability of this method to the site in question. The calculation of EPDC is discussed in detail in Section 2.3.2.

2.3.2 Statistical techniques already applied to California measurements

The cumulative population-weighted exposure hours statistical technique was already applied to California measurements in areas surrounding the sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs (California Air Resources Board, 1995; Popejoy, 1999) for 1981 to 1996. This technique computes the total exposure to exceedance concentrations of ozone for an entire air basin.

Cumulative ozone exposure is a different performance statistic than those associated with exceedances (as described earlier in this report). The determination of exposure hours directly considers health impacts while exceedance duration and thresholds indirectly consider health impacts. Cumulative exposure hours can be assessed using the following perspectives:

- "Hotspot" perspective – only considers the locations in an air basin where the potential for adverse health effects is greatest;
- Areawide perspective – treats all locations in the air basin as equal (in terms of population); and
- Per-capita average perspective – weights the locations in the air basin according to their associated population numbers.

This analysis involves the determination of the annual exposure to concentrations over the California Ozone Standard. When a per-capita average perspective is selected (Popejoy, 1999), this statistic is computed per average person and is expressed as pphm-hours. For

example, an exposure to 12 pphm for an hour is 3 pphm-hours (12-9 pphm x 1 hour = 3 pphm-hours), and an exposure to 10 pphm for 3 hours is also 3 pphm-hours (10-9 pphm x 3 hours = 3 pphm-hours). To perform the analysis, one must:

- Compute the total hours above the California Ozone Standard by site in an air basin;
- Interpolate the total hours between the sites; and
- Weight the cumulative exposure hours by population (Popejoy uses 1990 census tracts) to give exposure for the average person.

The ARB (California Air Resources Board, 1995) has performed these calculations for many sites and air basins from 1981 to 1993. Popejoy extended these analyses to 1996 in an internal ARB Study and plans to extend them further when the 1999 measurements are complete. Both investigators base their exposure hour calculations on the routine ozone concentrations at the site, and not anomalous ozone episodes that might be the result of downwind transport of precursors to a different region. This prioritizes the average ozone exceedances at a site over the anomalous ozone exceedances and results in a lower cumulative exposure hour determination than was actually experienced in the air basin.

2.3.3 Statistical technique not employed in this report

An additional statistical technique has been developed and applied to air quality measurements in the Eastern United States for 1988 to 1995 (Husar and Renard, 1997). This technique classifies high maximum ozone days according to wind patterns to elucidate the contribution of transport to ozone formation. This technique was not employed here because of the need for concurrent measurements that were not available and because the technique is numerically intensive and requires substantial manual data processing.

This method is not a meteorological adjustment technique, nor can it be used as a tool to predict ozone concentrations under specific meteorological conditions. Instead, it is a screening technique to investigate the issue of transport in relation to the observed ozone concentrations. Husar and Renard (1997) assume that the ozone concentration at a given location and time is composed of three components:

1) Tropospheric background ozone from natural biogenic and stratospheric sources;
2) Regional ozone from anthropogenic sources that are more than 100 km from the site;
3) Local ozone from anthropogenic sources that are less than 100 km from the site.

The dependence of ozone concentration on transport is analyzed by classifying the existing ozone concentration measurements into wind direction and wind speed bins, followed by concentration averaging in each bin. By classifying the meteorology and correlating the cases with the observed ozone concentrations, the authors develop general theories and approximate contributions to the observed ozone concentrations. The classification analysis requires at least

10 years of complete ozone, wind direction, and wind speed measurements and focuses on identifying the contribution of transported ozone to the measured ozone.

2.3.4 Adjustment techniques employed in this report

The two adjustment techniques that were considered in this work employ similar numerical techniques to remove the influence of particular events or conditions from the analyses. Both the expected peak day concentration (EPDC) and the native variability techniques were developed at the ARB (Larsen et al., 1990; California Air Resources Board, 1993). These techniques do not relate the observed ozone concentrations to meteorological measurements. Therefore, they cannot be used to adjust the ozone measurements to remove the influences of meteorology in specific. Rather, these techniques are used, in general, to remove variability from the ozone measurements that occur on time scales shorter than a year. The EPDC is analogous to the second highest maximum daily ozone concentration indicator. However, the EPDC differs from this indicator in that it is a hypothetical value that is based on a reprocessing of the ozone measurements to remove the bias of anomalous events. The Native variability technique results in a very different indicator. It is used to place confidence limits on the indicators (such as EPDC or 3-yr running average exceedance concentration) that are developed from the ozone measurements. The confidence limits differ from the analysis uncertainties discussed in Section 2.1 of the report. Native variability is the uncertainty in the ozone measurements that occurs as a result of normal meteorological and atmospheric variability (excluding anomalous events), whereas the analysis uncertainty is the standard deviation in the ozone concentrations that are averaged to compute a statistic (e.g., average exceedance concentration).

The analysis investigates EPDCs as a function of early morning precursor concentrations to gain insight into the effects of the emissions on the observed ozone concentrations. The analysis was performed for the PAMS Type 2 sites where precursor emissions are anticipated to be the greatest, and for the PAMS Type 2-like ARB sites.

The annual EPDC is a statistic that is used with the observed ozone exceedance concentrations to determine whether areas are in attainment or nonattainment of the California Ozone Standard. It does not represent the ozone concentration that is expected to occur once per year, but it is instead a hypothetical concentration that is similar to the second highest (Rank 2) annual exceedance concentration that was discussed in Section 2.3.1. It is determined from three consecutive years of daily smoothed, daily maximum ozone concentrations. The data are smoothed using the following process (where the upper percentiles of the daily maximum ozone concentrations may or may not be in exceedance of the 1-hr Ozone NAAQS or the California Ozone Standard):

- Perform an exponential-decay curve fit of the top 220 daily maximum ozone concentrations (upper 20^{th} percentile of the daily maximum ozone concentrations);
- Perform an exponential-decay curve fit for the top 119 daily maximum ozone concentrations;

- Perform an exponential-decay curve fit for the top 118 daily maximum ozone concentrations;
- Perform an exponential-decay curve fit for the top 56 daily maximum ozone concentrations;
- Perform an exponential-decay curve fit for the top 55 daily maximum ozone concentrations (upper 5th percentile of the daily maximum ozone concentrations); and
- Determine a weighted-average of the 165 fits, where the quality of each individual curve fit determines the weight the fit receives in the weighted-average.

The weighted-average of the top 20th percentile of the daily maximum ozone concentrations that were experienced in three years is intended to prioritize the maximum concentrations that were typical for the area. Conversely, assigning low coefficients to the poor exponential-decay curve fits minimizes the influence of the maximum concentrations that were anomalous ozone events for the area. Hypothetically, these anomalous daily maximum ozone concentrations will not follow the observed exponential-decay trend as well as the typical daily maximum ozone concentrations. While this is not a meteorological adjustment technique, many of the anomalous daily maximum ozone concentrations might be the result of anomalous meteorological events.

The EPDC concentration is computed from the weighted-average curve fit of the top 20th percentile of three consecutive years of daily maximum ozone concentrations (or the smoothed daily ozone concentrations). The EPDC concentration corresponds to the daily maximum ozone concentration where 99.7 percent (364 days/365 days) of the area under the weighted-average curve falls below the top 20th percentile of the smoothed measurements. In this way, the EPDC is similar to the 2nd highest annual ozone exceedance concentration, although it is only a hypothetical concentration because it is based on the smoothed daily maximum ozone concentrations and not the actual daily maximum ozone concentrations. **Figure 2-3** illustrates the distribution of three consecutive years of ozone exceedance concentrations for the Los Angeles North Main Street site for 1995-1997. The first graph illustrates the entire measurement set and the second graph illustrates the upper 20th percentile of the measurement set. **Figure 2-4** illustrates the weighted-average of the upper 20th to upper 5th percentile of the exceedance concentrations, and the identification of the EPDC concentration (144.8 ppb) for the Los Angeles North Main site for 1997.

The native variability analysis calls for a comparison of the analysis uncertainty and the native variability of the daily maximum ozone concentrations. Both types of variability are intended to place limits on the parameter that is being analyzed to caution users from discerning upward or downward trends in the measurements that are actually within the uncertainty or variability of the measurement set. In this case, the variability will be used to assess trends in the average annual maximum daily ozone concentrations.

The measured variability is based on the range of daily maximum ozone concentrations that actually occurred within a single year. All of these concentrations would be used to compute an average annual daily maximum ozone concentration and the measured variability

would be determined for each year of complete measurements and used to set confidence limits on the trend analyses. The measured variability is adequately demonstrated using standard deviations about the average ozone daily maximum concentrations. Box and whisker plots can also be used to demonstrate this variability in a more complete way and are used in this work. These plots illustrate the 25^{th}, 50^{th} (median), and 75^{th} percentiles of the measurements, and the outlier points.

Like the EPDC technique, the native variability technique is not based on the distribution of a single year of observed concentrations. Rather, it is based on the distribution of numerous hypothetical single years of observed concentrations. It attempts to represent the uncertainty associated with variations in the ozone concentrations over the 3-yr time period, although it is not a meteorological adjustment technique. Instead, the native variability statistic has been shown to be sensitive to meteorological changes but not variable with respect to them. In order for this to be the case, emissions into the region (that are known to influence ozone formation) need to be constant over the 3-yr time period for which the measurements are used, because the calculation involves a directed, but random, sampling from the three years of measurements. Even if there were no changes to the emission standards in a region over the 3-yr period of time in question, population growth over the time period raises questions about the utility of this approach.

Anomalous ozone concentrations are considered to be indicative of regional transport and are automatically removed from the measurement set; this demonstrates the different approach of this statistic. This statistic is more complex to calculate but can be determined using a program developed by the ARB (California Air Resources Board, 1993). Unlike the measured variability, the native variability is generally determined only for the initial three years and final three years of the span of the trend analysis. In this analysis, the native variability was determined on an annual basis to enable a comparison of the standard and native variability.

The calculation requires three consecutive years of concentrations (in this case daily maximum ozone concentrations) and can be applied to any statistic that is determined from the daily concentrations (e.g., average maximum daily ozone concentration, 3-yr running average of the maximum ozone concentration, EPDC, and population-weighted exposure hours). In this work, native variability was determined for the annual average daily maximum ozone concentration. The native variability program, RECRATE, uses a bootstrapping procedure to develop two hundred hypothetical single years of daily maximum ozone concentrations. It also applies an exponential-tail method to fit an exponential-decay curve fit to the top 20^{th} percentile of the measurements in each hypothetical year (similar to the method of EPDC determination). The program then calculates the "native" standard deviation of the 200 different exponential-decay curve fits. The native variability limits are based on this standard deviation and are specific to the percent level of confidence the user wants to associate with the trend. The ARB generally assumes a 95 percent confidence level and computes the composite native variability limits using the following procedure (California Air Resources Board, 1993):

- Determine the native variability of the initial (nv_I) and final (nv_F) three years of consecutive daily maximum ozone concentrations using the ARB program RECRATE;
- Identify the percent level of confidence of the trend analysis. This percent confidence is associated with a "Z(percent confidence)" concentration and is documented in the ARB guidance document, where Z(95 percent confidence) = 1.64;
- Calculate the composite native variability limits (CNVL) at the desired percent confidence level above 50 percent. Note that the initial and final average daily maximum ozone concentrations (DMO_I, DMO_F) are only valid at a confidence level of 50 percent: CNVL(percent confidence) = $\pm$ Z(percent confidence) * $(nv_I^2 + nv_F^2)^{1/2}$
- Determine the discernable trend over the initial and final average daily maximum ozone concentrations: Discernable trend = $| DMO_I - DMO_F |$ - CNVL(percent confidence)

Figure 2-5 demonstrates how to interpret the native variability limits on EPDC estimates to discern a trend at a California site.

A trend from the initial year to any final year is clear when the difference between the baseline ozone concentration and the 95 percent confidence limits on the final ozone concentration is clear. In Figure 2-5, all of the EPDCs are lower than the baseline EPDC of 155 ppb. However, when the 95 percent confidence limits on the native variability of these EPDCs are considered, all of the EPDCs are higher than the baseline EPDC. In 1996, the native variability limits encompass the baseline ozone concentration. In 1993, there is minimal net change in the EPDC when native variability is considered. In 1994, a clear trend is observable, because there is a substantial net change from the baseline EPDC. Because this method assumes that emission sources are constant within each 3-yr increment of time, this would suggest that the minimal variability in the ozone concentrations is a result of atmospheric or meteorological variability. Important factors in the lower ozone concentrations could include significant differences in meteorology or dramatic emission changes.

2.3.5 Adjustment techniques that were already applied to California measurements

Two adjustment techniques were applied to California measurements at or near the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs. Both methods adjust the ozone measurements to remove the effects of meteorology from the measurements by establishing a baseline meteorological condition against which all other meteorological conditions are compared. However, the two methods differ in their approaches to the adjustment.

Cox and Chu fit all of the daily maximum ozone concentrations to a probability distribution that ignores days on which the maximum daily ozone concentration is not well represented in the distribution. It is likely that these days are the result of anomalous atmospheric and meteorological events. Rao and his coworkers compare the variability in ozone measurements to variability in meteorological measurements. They consider three

different time-scales in their analyses, in order to elucidate the contributions from anomalous atmospheric and meteorological variations, seasonal meteorology patterns, and long-term emission changes to the observed daily maximum ozone concentrations.

Cox and Chu Technique

Cox and Chu (1998) adjust the ozone measurements for meteorology by developing a relationship between maximum daily ozone concentration and several meteorological parameters. A bootstrapping procedure is used to generate many years of daily maximum ozone concentrations from the actual set of annual measurements. The bootstrapped measurements are fitted to a Weibull probability distribution, and the parameters of the distribution are allowed to vary as a log-function of surface temperature (ST) and wind speed (WS) and the log of the measured ozone:

$$WPD_i = \exp\{-(Y/\sigma_I)^{\lambda}\};$$

$$\sigma_I = \exp\{\Sigma\beta_j * M_{ij} + \xi T\};$$

$$\Sigma WPD_i = N*(1-P)$$

Where:

- Y = ozone exceedance concentration (95 ppb or 125 ppb)
- I = total number of days (365)
- J = Total number of meteorological parameters (2: ST and WS)
- λ = Weibull distribution shape parameter
- β_j = Regression coefficient for the j^{th} meteorological value
- M_{ij} = Meteorological parameter (ST or WS)
- ξ = Annual trend rate
- T = Year

The smoothed (or adjusted) ozone concentrations are supposed to represent ozone concentrations that would most likely have occurred (within the confidence limits) had the meteorological variables been the same each year. The Weibull probability distribution model was chosen because it has been widely used to describe air pollution distributions and had been found to be particularly suitable for describing the annual distribution of daily maximum ozone (Johnson, 1979).

This process smoothes the actual ozone concentrations by minimizing anomalous events in a way that is similar to the native variability calculations performed by the ARB. Both methods define confidence intervals that are used to place limits on the calculated parameters (whether it is adjusted ozone concentrations or the native variability of the ozone concentrations). However, this method differs from the ARB technique in several ways:

- Cox and Chu use a Weibull distribution and the ARB use an exponential tail fit;

- Cox and Chu fit all of the daily ozone concentrations to the distribution while the ARB method only fits the top 20th percentile of the concentrations;
- Cox and Chu estimate the meteorological component of the fit measurements while the ARB does not directly relate the ozone concentrations to meteorological parameters;
- Cox and Chu adjust the ozone concentrations to scale the meteorological component of the measurements from the current meteorological (T, WS) conditions to typical meteorological conditions, while the ARB uses information from the exponential tail fit to determine the "native variability" or uncertainty of the ozone concentrations;
- Cox and Chu uses a running average of the meteorology and ozone concentrations over an 11-year period as the baseline while the ARB uses the first years in a period over which the trends are being estimated as the baseline.

The Cox and Chu method of ozone adjustment is intensive and requires special software to perform the analysis. Their method also requires complete annual sets of all of the parameters used in the analysis (in this case ozone, surface temperature, and wind speed). The results were available for the 1986 to 1997 time period for Sacramento, Bakersfield, Fresno, Los Angeles, and San Diego.

Work by these and other researchers to fit the ozone measurements to a probability distribution have considered more meteorological parameters including surface temperature, relative humidity, wind speed and wind direction (Cox and Chu, 1993; 1996; Holland et al., 1999). However, the utility of these parameters to this project is limited by the availability of the additional measurements required by the methods.

Rao and Zurbenko Technique

Many temperature adjustment methods, including those of Rao and Zurbenko (1994), develop relationships between ozone and meteorological variables. However, Rao and Zurbenko filter the ozone and meteorological measurements to remove the short-term component of the measurements before developing any relationships. Most other methods use the original set of ozone and meteorology measurements in the relationship between the measurements. Rao and coworkers assert that when important short-term, seasonal and long-term temporal scales are considered together (as they are in most other analyses), false relationships between the observed ozone and meteorology are drawn. They identify three time scales that when added, result in the observed ozone variations on which most others base their relationships:

1) Short-term, weather-driven ozone fluctuations W(t): These fluctuations are usually a weak relationship of the meteorological variables.
2) Seasonal ozone fluctuations S(t): These fluctuations in the observed ozone have been demonstrated to have high correlation to seasonal meteorological variables like solar radiation and temperature.

3) Long-term ozone fluctuations e(t): Although these fluctuations are assumed to be the result of long-term changes in emissions into the region, Rao and coworkers demonstrated that some climate processes contribute to this time scale of ozone fluctuations. However, this fluctuation is assumed to be the temperature-independent trend in ozone concentrations.

$$X(t) = W(t) + S(t) + e(t);$$

The short- and long-term trends in the observed ozone are separated from the seasonal variation in the observations using the Kolmogorov-Zurbenko ($KZ_{m,p}$) filter. The $KZ_{m,p}$ filter is a low pass filter produced by repeated iterations of a simple moving average of both the ozone and meteorological measurements. The seasonal component of the observed ozone concentrations is estimated by subtraction.

$$W(t) = X(t) - KZ_{15,5};$$

$$e(t) = KZ_{365,3};$$

$$S(t) = KZ_{15,5} - KZ_{365,3};$$

After applying the KZ filters to the ozone and meteorological measurements, the seasonal and long-term components are subtracted from the original measurements and used to develop a relationship between meteorologically dependent ozone and meteorology. The relationship is based on a linear regression of the filtered log of ozone concentrations (O_{kz}) and filtered temperature (T_{kz}) that is lagged by 19 days:

$$O_{kz}(t) = aT_{kz}(t+19) + b;$$

Where:

a,b = Fitted parameters
t = Time

The meteorologically independent ozone concentration is the difference of the original measured ozone concentration and the estimated meteorologically dependent ozone concentration (or the long-term component e(t)).

$$\text{Adjusted ozone} = O(t) - \{aT_{kz}(t+19) + b\};$$

Rao, Zurbenko and their coworkers considered meteorological parameters besides surface temperature in their analysis, including dew point temperature and depression, specific humidity, wind speed, opaque cloud cover, ceiling height, and solar radiation. However the improvement to the model performance as a result of including more than temperature was demonstrated to be small (Rao and Zurbenko, 1994; Rao et al., 1995; Zurbenko et al., 1995; Anh et al., 1997; Flaum et al., 1996; Milanchus et al., 1997; 1998). For some sites, such as the Los Angeles North Main Street site, the difference between ozone that was adjusted for

only surface temperature and the original measured ozone was not found to be statistically different. Porter (1996) applied these techniques to Folsom, Emma Wood Beach, El Rio, and Los Angeles from 1983 to 1995. Upon our request, Porter (1999) also applied these techniques to the Del Paso Manor, Arvin, Parlier, Los Angeles, and San Diego sites in California from 1988 to 1997.

2.3.6 Adjustment techniques not employed in this report

Several adjustment techniques have been developed and applied to air quality measurements in the Northeastern United States. However, these techniques were not employed for the following reasons:

- Assumptions of the technique are questionable and are believed to limit the utility of the technique; or
- The technique is numerically intensive and requires substantial manual data processing or special software; or
- Measurements that are needed for the analyses are not available for the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego and Ventura MSAs.

In the cases where simple linear regressions of the data were performed, fundamental assumptions of the technique were found to be questionable. As a result, the effort to compile the measurements into a form that is needed for the analysis was not considered to be worthwhile. In the cases involving nonlinear regressions of the data, the utility of the techniques were considered to be questionable; however, it was the lack of concurrent measurements that prohibited its application to the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs. In the case of the Classification and Regression Tree (CART) technique, the analysis is considered to be constructive but was not performed because concurrent measurements were unavailable, and because extensive manual data processing and special software were required.

Linear regression of measured ozone against meteorology adjusts for meteorology by considering the effects of multiple meteorological variables on ozone formation. Davidson (1993) assumes a linear relationship between the temperature at 850 mb (T850) and measured ozone concentrations. His analysis was performed for the South Coast air basin for the period from 1976 to 1984, using an average meteorological concentration to define the base case. Zeldin et al. (1990) assumed a linear relationship between some inversion parameters, synoptic parameters and surface pressure gradients, and measured ozone concentrations. They performed their analysis on California data from 1981 to 1989, using parameters in the early years as base conditions. Cohanim et al. (1998) also assumed a linear relationship but use T850 as an indicator of all other meteorological parameters. They performed their analysis on California data from 1987 to 1996, using the average annual T850 for the period 1987 to 1996 to define the base case. However, the fact that the relationship between ozone and meteorology is quite complex and is certainly not linear raises questions regarding the utility of

this approach. As a result, the coefficients of the fit gave no physical insight into the processes that dictate the ozone concentrations. Further, high ozone concentrations are consistently under-predicted by this type of model because the least-squares fitting procedure used in linear regression is designed to limit the overall mean square error. Since high ozone concentrations tend to occur less frequently than moderate concentrations, they do not play a major role in determining the regression coefficients. This can be an issue even when the low-ozone days are removed from the measurement set of daily ozone concentrations. This method can still be used to elucidate general trends but was not used in the current work due to unavailable temperature measurements at 850 millibars.

Nonlinear regression of measured ozone against meteorology adjusts for meteorology by considering the effects of multiple meteorological variables on ozone formation and has been employed by Bloomfield et al. (1996) and Holland et al. (1999). The relationship between the ozone and meteorology is assumed by these authors to be nonlinear. Bloomfield et al. (1996) assumed a nonlinear relationship between temperature, wind speed, and relative humidity and measured ozone concentrations. They performed their analysis on Chicago from 1981 to 1991 using mean parameters over the time period as base conditions. Holland et al., assume a nonlinear relationship between temperature, wind speed, wind direction and relative humidity, and measured ozone concentrations. They performed their analysis on the CASTnet sites in the eastern United States from 1989 to 1995, using parameters in the early years as base conditions. However, the coefficients of the fit gave no physical insight into the processes that dictate the ozone concentrations. Further, high ozone concentrations are also consistently under-predicted by this type of model because the least-squares fitting procedure used in nonlinear regression is designed to limit the overall mean square error. Since high ozone concentrations tend to occur less frequently than moderate concentrations, they do not play a major role in determining the regression coefficients.

The CART regression tree method can be used to adjust ozone concentrations to remove the meteorological component of the measured ozone. It is used to examine the dependence of ozone concentration patterns on the prevailing meteorological conditions, but it requires extensive information on which the classifications are based, including temperature, number of daylight hours, ceiling height, surface pressure, rainfall, relative humidity, wind speed, and wind direction. The advantage of the CART approach over simple linear regression is that if there were specific meteorological conditions associated with the high ozone days, such days will be placed in a separate group; thus, the compromise involved in fitting a single linear equation to all of the measurements is eliminated. The classifications are performed using special CART software to segregate the ozone concentrations and episodes through the growth of a binary decision tree based on the concurrent meteorological parameters. Individual linear regressions of the ozone concentrations against the meteorological parameters are performed for decision tree branch. Establishment of average ozone and meteorological concentrations for each node of the regression tree allows for an adjusted ozone concentration to be determined. However, fluctuations from year to year in the results obtained using this type of analysis have been found to be considerable for some areas; thus questions arise regarding the effectiveness of performing the unwieldy task of compiling and processing the measurements for this analysis. Stoekenius (1990) and Deuel and Douglas

(1996), for example, have applied this method to data in the eastern United States for the period from 1979 to 1988.

2.4 SUMMARY

Section 2 focuses on the background information that was used to develop the technical approach employed in this report. The data available for trends analyses at the PAMS and long-term trend sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs were summarized. The uncertainties of data were discussed. The available statistical and adjustment techniques described; **Table 2-6** summarizes these techniques and provides pros and cons for each technique. The information in this table should facilitate future trends analyses.

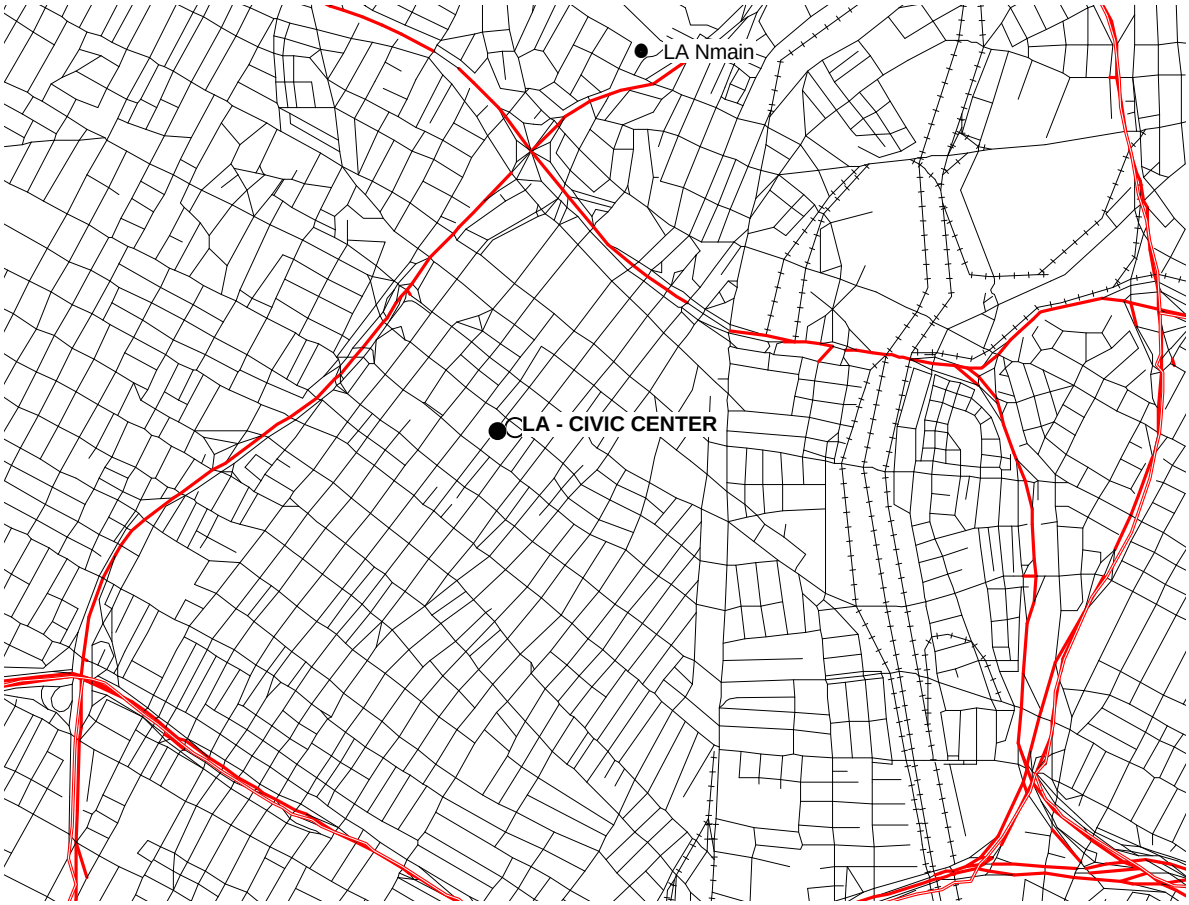

Figure 2-1. Location of the North Main Street PAMS site and the Civic Center NWS station at LAX Airport.

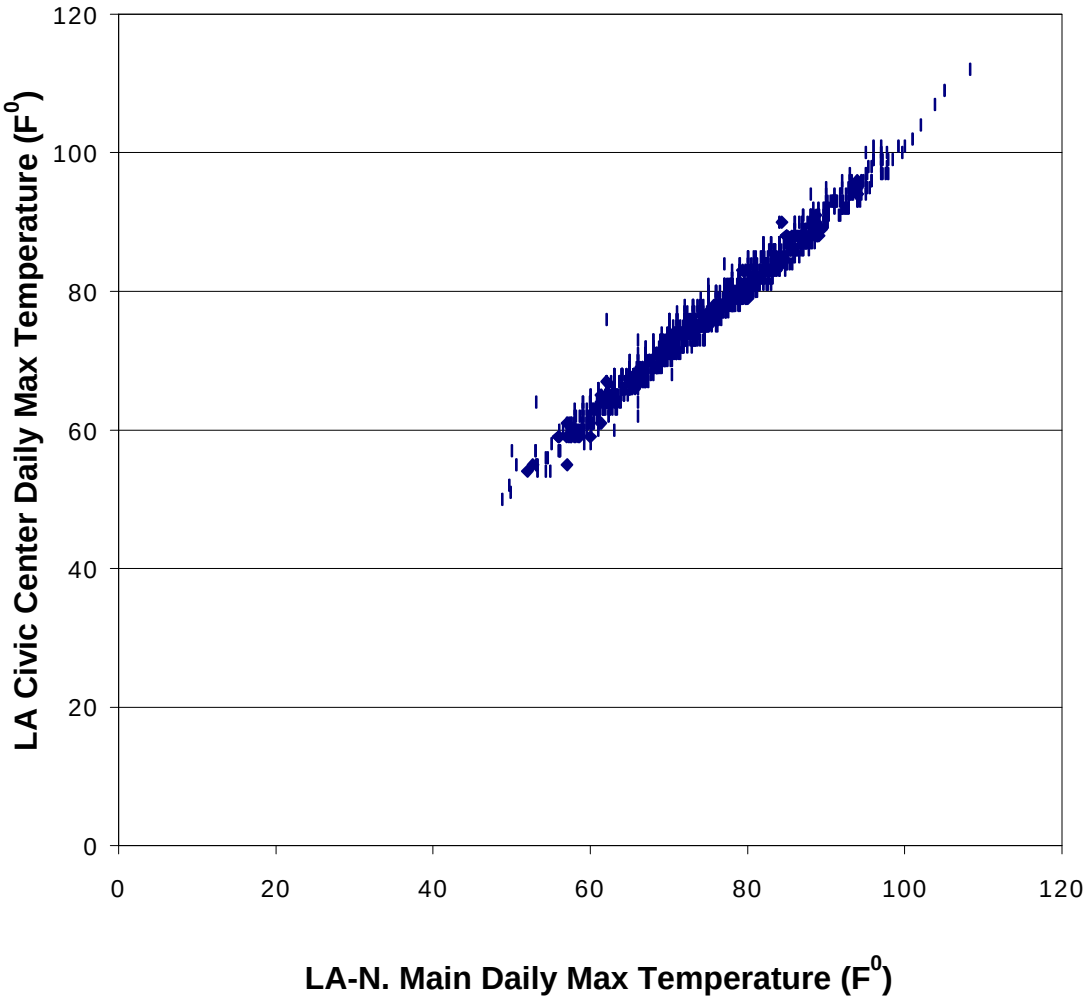

Figure 2-2. Comparison of temperature measurements made in Los Angeles at the North Main Street PAMS site and the Civic Center NWS station at LAX Airport.

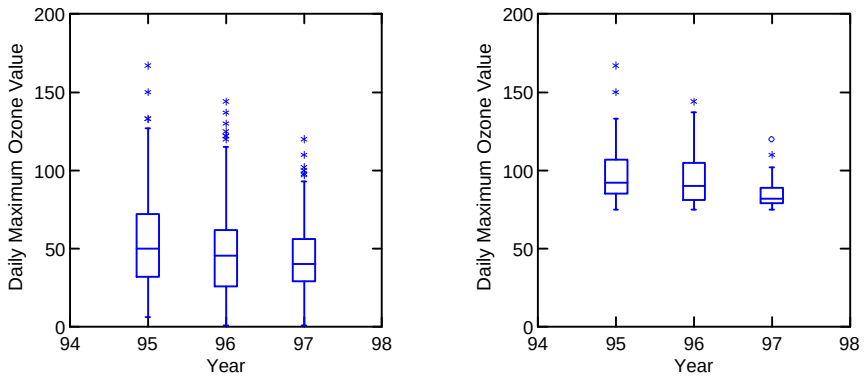

Figure 2-3. Los Angeles North Main Street site daily maximum ozone concentrations for 1995-1997. The boxes show the 25th, 50th (median), and 75th percentiles. The whiskers have a maximum length of 1.5 times the length of the box (interquartile range IR). If there are data outside this range, the outliers are also further identified with asterisks representing points that fall within three times the IR and circles for data beyond this.

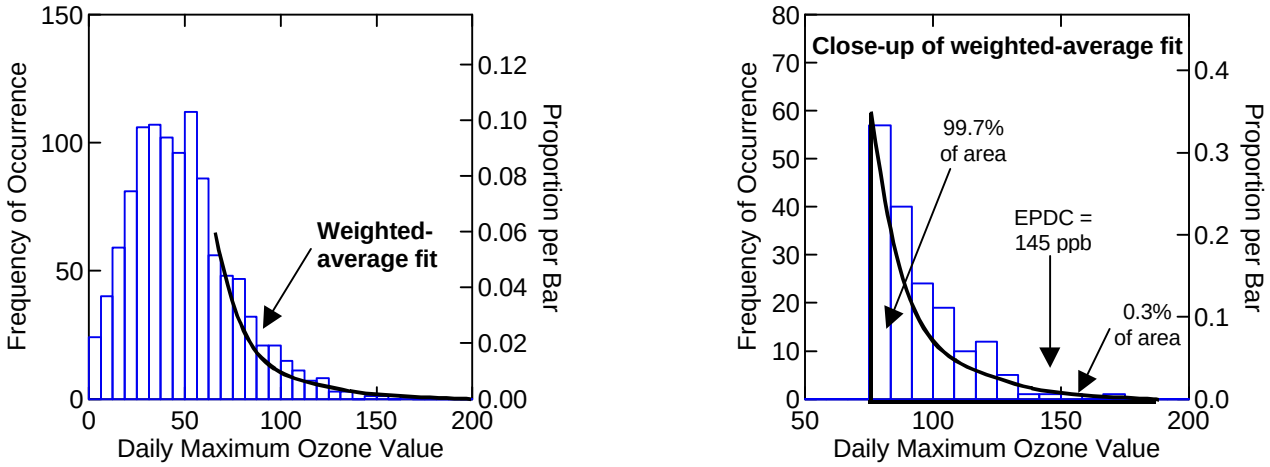

Figure 2-4. Identification of the EPDC at the Los Angeles North Main Street site in 1997.

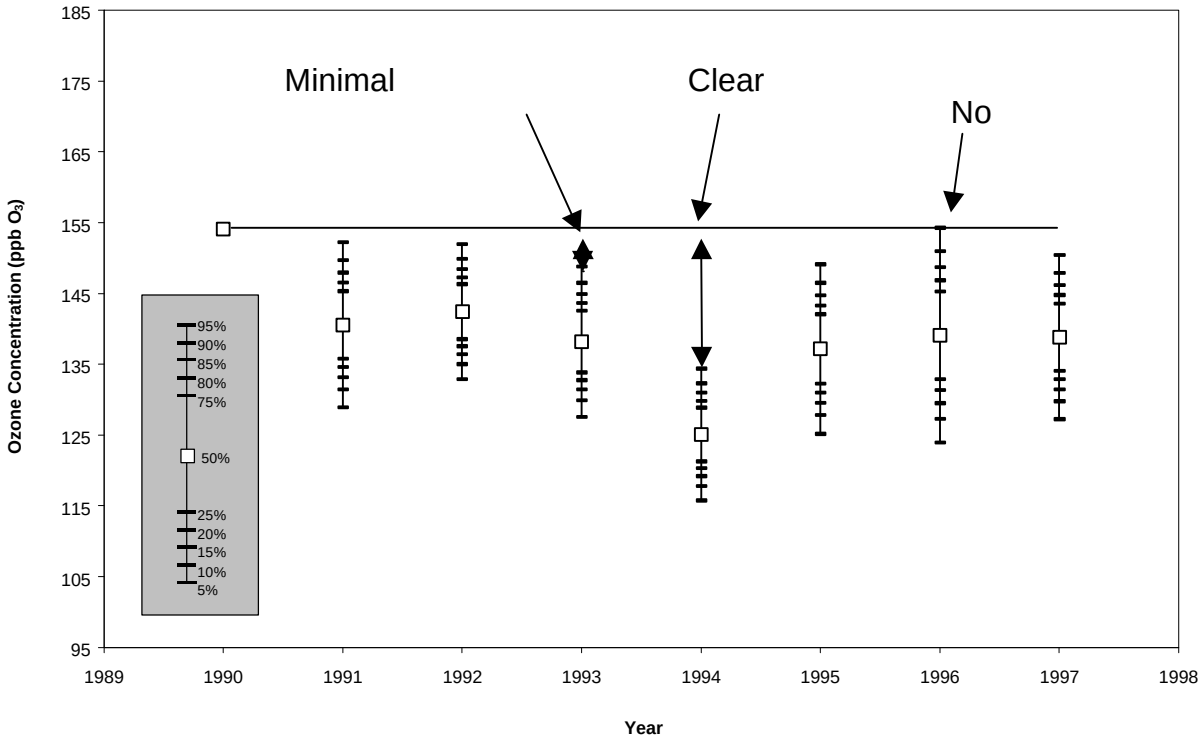

Figure 2-5. Use of native variability to interpret a trend in the EPDCs.

Table 2-1. Typical measurement precisions.

Measurement	Approximate uncertainty	Example measurements	Approximate uncertainty
Ozone	± 4 percent	150 ppb	6 ppb
NO_x	± 6 percent	50 ppb	3 ppb
Total NMHC	± 10 to 20 percent	200 ppbC	20 to 40 ppbC
Temperature	± 1 ^{0}F	100 ^{0}F	1 ^{0}F

Table 2-2. Summary of measurement completeness investigations.

Site Name	MSA	Site Type [a]	Ozone	NO_x	Temperature	Potential Measurement Concerns
Elk-Grove Bruceville	Sacramento	1	1993 – 1998	1994 - 1998 [b]	1996 - 1997	In 1994, limited NO_x measurements available. In 1996, limited temperature measurements available.
Del Paso Manor	Sacramento	2	1987 – 1998	1994 - 1998	1996 - 1997	None.
Folsom	Sacramento	3	1988 - 1996			Site relocated to New Folsom location on 9/1/96.
New Folsom	Sacramento	3	1996 - 1998	1996 - 1998 [b]	1996 - 1997	In 1996, limited NO_x measurements available.
Golden State Avenue	Bakersfield	2	1994 - 1997 [b]	1994 - 1997	1994 - 1997 [b]	In 1994, ozone measurements only available from 7/1 to 10/31. In 1994 and 1997, limited temperature measurements available.
Arvin	Bakersfield	1 and 3	1989 - 1998 [b]	1994 - 1998	1992 - 1993, 1995 - 1997 [b]	In 1989, ozone measurements only available from 6/1 to 10/31. In 1998, ozone measurements only available from 4/1 to 9/31. In 1997, limited temperature measurements available. No temperature measurements available in 1994.
Clovis-Villa	Fresno	2	1990 - 1997 [b]	1994 - 1997	1993 - 1997 [b]	In 1990, ozone measurements only available from 9/1 to 10/31. In 1993, 1994 and 1997, limited temperature measurements.
Fresno 1st Street	Fresno	ARB	1990 - 1998	1994 - 1998	1992, 1993, 1995 - 1997	No temperature measurements available in 1994.
Parlier	Fresno	3	1987 - 1998 [b]	1994 - 1998 [b]	1995 - 1997 [b]	In 1998, ozone measurements only available from 4/1 to 6/31. In 1998, limited NO_x measurements available. In 1995 and 1997, limited temperature measurements available.
San Diego 12th Street	San Diego	ARB	1989 - 1998	1993 - 1998	No measurements available	In 1989, ozone measurements only available from 8/1 to 10/31. In 1998, ozone measurements only available from 4/1 to 9/31. No temperature measurements available.
Los Angeles N. Main	Los Angeles	ARB	1987 - 1998	1987 - 1998	1990 - 1992, 1994 - 1997 [b]	In 1997, limited temperature measurements available. No temperature measurements available in 1993.
Emma Wood Beach	Ventura	1	1987 - 1998	1987 - 1998	1991, 1993 - 1996 [b]	In 1993 and 1996, limited temperature measurements available. No temperature measurements available in 1992.
El Rio	Ventura	2	1987 - 1998	1987 - 1998	1993 - 1996 [b]	In 1993 and 1996, limited temperature measurements available.
Simi Valley	Ventura	3	1987 - 1998	1987 - 1998	1991, 1993 - 1996 [b]	In 1996, limited temperature measurements available. No temperature measurements available in 1992.

MSA: Metropolitan Statistical Area

[a] Type 1: upwind and background site, Type 2: maximum ozone precursor emissions site, Type 3: maximum ozone concentration site, Type 4: extreme downwind monitoring site, ARB: ARB long-term trend site.

[b] Incomplete annual set of measurements, based on less than 75 percent completeness of reported measurements from 5/1 to 10/31.

Table 2-3. List of years and sources of supplemented NWS temperature measurements.

Site Name	MSA	Site Type [a]	Temperature	Source of Supplemented Temperature Measurements
Elk-Grove Bruceville	Sacramento	1		No temperature analyses performed.
Del Paso Manor	Sacramento	2	1988 - 1997 [b]	Measurements from 1988 - 1995 from Sacramento Metro Airport.
Folsom	Sacramento	3		No temperature analyses performed.
New Folsom	Sacramento	3		No temperature analyses performed.
Golden State Avenue	Bakersfield	2		No temperature analyses performed.
Arvin	Bakersfield	1 and 3	1988 - 1997 [b]	Measurements from 1988 - 1995 from Bakersfield Airport.
Clovis-Villa	Fresno	2	1988 - 1997 [b]	Measurements from 1988 - 1995 from Fresno Air Terminal.
Fresno 1st Street	Fresno	ARB	1988 - 1997 [b]	Measurements from 1988 - 1995 from Fresno Air Terminal.
Parlier	Fresno	3	1988 - 1997 [b]	Measurements from 1988 - 1995 from Fresno Air Terminal.
San Diego 12th Street	San Diego	ARB	1988 - 1995 [b]	Measurements from 1988 - 1995 from San Diego Airport.
Los Angeles N. Main	Los Angeles	ARB	1988 - 1997 [b]	Measurements from 1988 - 1995 from LAX Airport.
Emma Wood Beach	Ventura	1		No temperature analyses performed.
El Rio	Ventura	2		No temperature analyses performed.
Simi Valley	Ventura	3		No temperature analyses performed.

MSA: Metropolitan Statistical Area

[a] Type 1: upwind and background site, Type 2: maximum ozone precursor emissions site, Type 3: maximum ozone concentration site, Type 4: extreme downwind monitoring site, ARB: ARB long-term trend site.

[b] The incomplete set of annual temperature measurements was supplemented with temperature measurements made at NWS stations at nearby airports from 1988 to 1995.

Table 2-4. NAAQS and California Standards for ozone.

Standard	Sampling Interval	Exceedance Concentration	Exceedance Criteria
NAAQS	1-hr	0.12 ppm, based on daily maximum concentration	not to be exceeded more than once per year
NAAQS	8-hr	0.08 ppm, based on the fourth highest concentration averaged over four years	not to be exceeded
California	1-hr	0.09 ppm, based on daily maximum concentration	not to be exceeded more than once per year

Table 2-5. Example morning VOC/ NO_x (ppbC/ppb) thresholds.

VOC limited	Transitional	NO_x limited
< 10	10 to 20	> 20

Table 2-6. Comparison of adjustment techniques.

Method	Pros	Cons	Data Requirements
Expected peak day concentration (EPDC) (California Air Resources Board, 1993)	• Accounts for variability in the measurements.	• Does not explicitly account for meteorology. • Ignores the highest ozone days. • Requires daily observations over an entire year.	• Special software. • Daily maximum ozone concentration measurements for three consecutive years at minimum.
Native variability (California Air Resources Board, 1993)	• Accounts for variability in the measurements. • Estimates the uncertainty in a parameter that is used to assess trends using a different approach than a measurement uncertainty or an average standard deviation. • Can be performed using any parameter that is measured on a daily basis.	• Does not explicitly account for meteorology. • Ignores the highest ozone days. • To develop trending conclusions using this technique, the user must assume that emissions do not change over a running 3-yr period of time. • Requires daily observations over an entire year.	• Special software. • Daily maximum ozone concentration measurements for three consecutive years at minimum.
Meteorological adjustment using a filtering technique (Rao and Zurbenko, 1994; Rao et al., 1995; Zurbenko et al., 1995; Anh et al., 1997; Flaum et al., 1996; Milanchus et al., 1997; 1998; Porter, 1996)	• A meteorological adjustment technique. • Is intended to be used as a predictive tool. • Separates the ozone concentrations into different time scales to discern trends in the concentrations that are due to emissions changes.	• To develop trending conclusions using this technique, the user must assume that ozone concentrations that are not affected by meteorologically anomalous events can be fit to a periodic function. • Numerically intensive. • Most current versions of this technique use parameters that are not commonly measured and require some parameters to be modeled.	• Special software. • Daily maximum ozone concentration and daily maximum temperature measurements at minimum. • Daily maximum ozone concentration and daily maximum temperature, dew point temperature and depression, specific humidity, wind speed, opaque cloud cover, ceiling height, and solar radiation measurements at most.

Table 2-6. Comparison of adjustment techniques.

Method	Pros	Cons	Data Requirements
Meteorological adjustment using a probability distribution technique (Cox and Chu, 1998)	• A meteorological adjustment technique. • Is intended to be used as a predictive tool.	• To develop trending conclusions using this technique, the user must assume that ozone concentrations that are not affected by meteorologically anomalous events can be fit to a Weibull distribution. • Problem establishing a baseline – uses average parameters to define the base case. • Numerically intensive.	• Special software. • Daily maximum ozone concentration and daily maximum surface temperature at minimum. • Daily maximum ozone concentration and daily maximum surface temperature, relative humidity, wind speed and wind direction measurements at most.
Transported ozone estimation by analysis of wind speed and wind direction against measured ozone (Husar and Renard, 1997)	• Accounts for meteorology. • Considers a regional approach to ozone formation. • Does not fit ozone measurements to an equation.	• Not a meteorological adjustment technique. • Uses meteorological parameters that require substantial classification. • Uses parameters that are not available over a long enough period at the sites of interest.	• Daily maximum ozone concentration, daily wind speed and wind direction measurements.
CART (Classification and Regression Tree) analysis of ozone concentrations against numerous meteorological conditions (Stoekenius, 1990; Deuel and Douglas, 1996)	• Accounts for meteorology. • Does not fit ozone measurements to an equation.	• Not a meteorological adjustment technique. • Uses meteorological parameters that require substantial classification. • Numerically intensive. • Uses parameters that are not available over a long enough period at the sites of interest.	• Special software. • Daily maximum ozone concentration, daily maximum surface temperature, number of daylight hours, ceiling height, surface pressure, rainfall, relative humidity, wind speed, and wind direction measurements.

Table 2-6. Comparison of adjustment techniques.

Method	Pros	Cons	Data Requirements
Linear regression of ozone against meteorological parameters (Davidson, 1993; Zeldin et al., 1990; Cohanim et al., 1998)	• Accounts for meteorology. • Not numerically intensive.	• Not a meteorological adjustment technique. • Fits the overall nonlinear process of transport and reaction to a linear function. • No real insight or physical meaning of coefficients. • Can use meteorological parameters that are not widely measured.	• Daily maximum ozone concentrations and daily T850 at minimum. • Daily maximum ozone concentrations and inversion parameters, synoptic parameters, surface pressure gradients, and T850 measurements at most.
Nonlinear regression of ozone against meteorological parameters (Bloomfield et al., 1996; Holland et al., 1999)	• Accounts for meteorology. • Fits a nonlinear process to a nonlinear function. • Not numerically intensive.	• Not a meteorological adjustment technique. • No real insight or physical meaning of coefficients. • Uses parameters that are not available over a long enough period at the sites of interest. • Can use meteorological parameters that are not widely measured.	• Daily maximum ozone concentrations and daily temperature, relative humidity, wind speed measurements.

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3. RESULTS OVERVIEW

The findings of the statistical and adjustment analyses are presented and discussed in the following sections. Each MSA is discussed in a separate section. Each section provides an overview, a description of statistical analyses, a description of adjustment analyses, and a summary of air quality trends. The trends graphics that were not included in the report are presented in Appendices B through G.

Many statistics were considered in order to evaluate the changing air quality from a variety of perspectives at the selected sites. A consensus approach was taken in which more confidence was given to a conclusion, or trend, when several analyses, or indicators, supported it. Some of the indicators revealed clear trends, such as number of exceedance days and cumulative exposure hours. Other indicators did not reveal as clear a trend when analysis uncertainties were also considered, such as average exceedance concentrations. However, nearly all indicators suggested similar trends in the air quality at the selected sites.

Analysis uncertainties were used to investigate the confidence with which trends could be distinguished. The 3-yr running average exceedance concentrations were used to simply investigate the contribution of anomalous atmospheric and meteorological events on the measured daily maximum ozone concentrations. More rigorous approaches to investigate the uncertainty in the trends were also considered, including expected peak day concentrations, native variability estimates, probabilistic meteorological adjustment, and filter meteorological adjustment techniques. These techniques were used to investigate the confidence limits on the trends in ozone data when atmospheric and/or meteorological variability was removed from the measurements; the techniques were fully described in Section 2.

Figure 3-1 presents the spatial positioning of the selected PAMS sites. The NWS stations are also detailed on this figure; temperature measurements at these stations were used to supplement the temperature measurements at the selected sites from 1988 to 1995, as discussed in Section 2.

When all of the selected sites are considered, a statewide improvement in ozone air quality was observed from the late 1980s to the late 1990s. There was a clear reduction in the number of exceedance days that experienced ozone concentrations in excess of the California Ozone Standard at nearly all of the selected PAMS sites. **Figure 3-2** shows that each of the air basins also experienced a reduction in the number of cumulative exposure hours to elevated ozone concentrations.

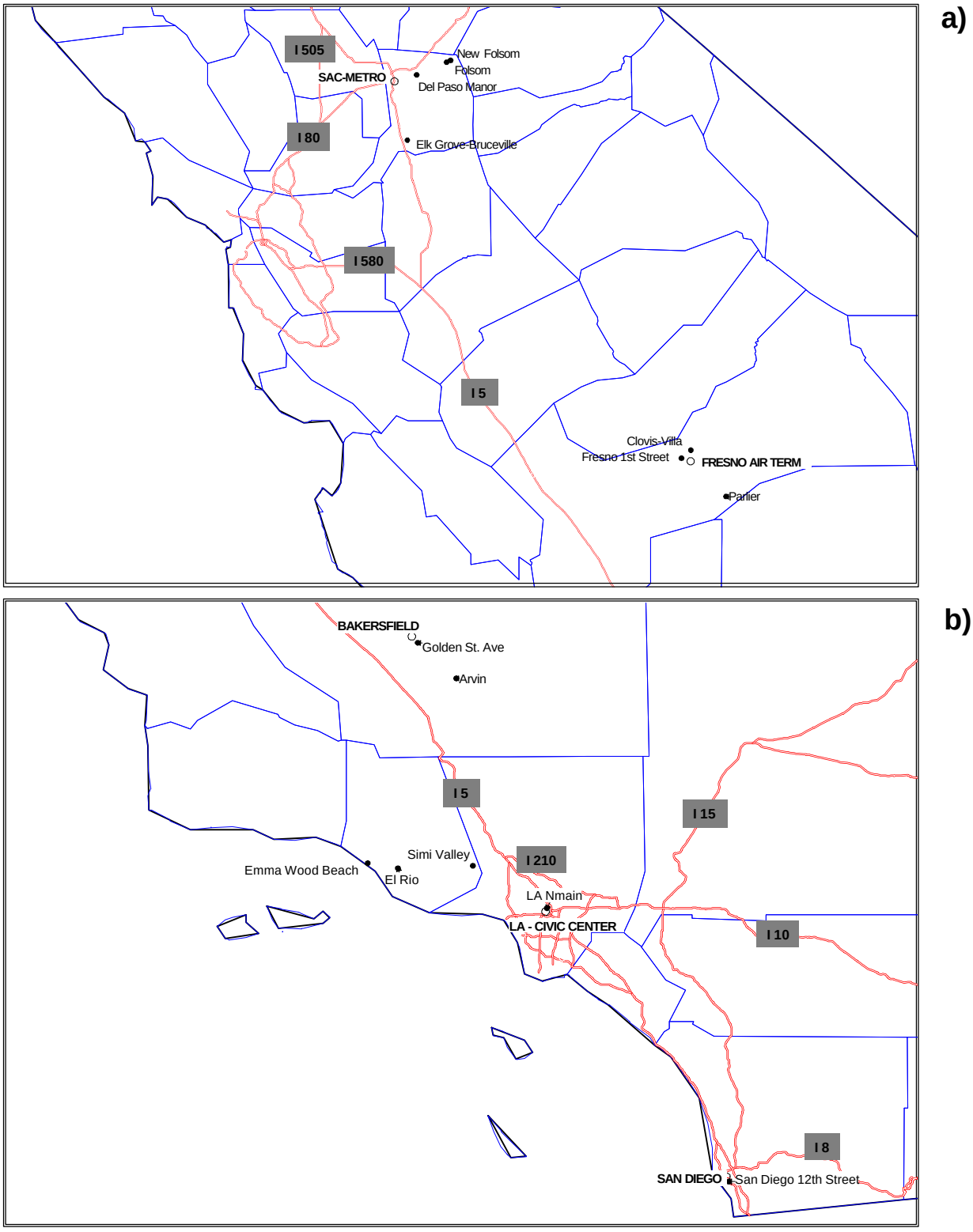

Figure 3-1. Selected PAMS sites (•) and NWS stations (o): a) Northern California and b) Southern California. Major freeways are indicated on the plots.

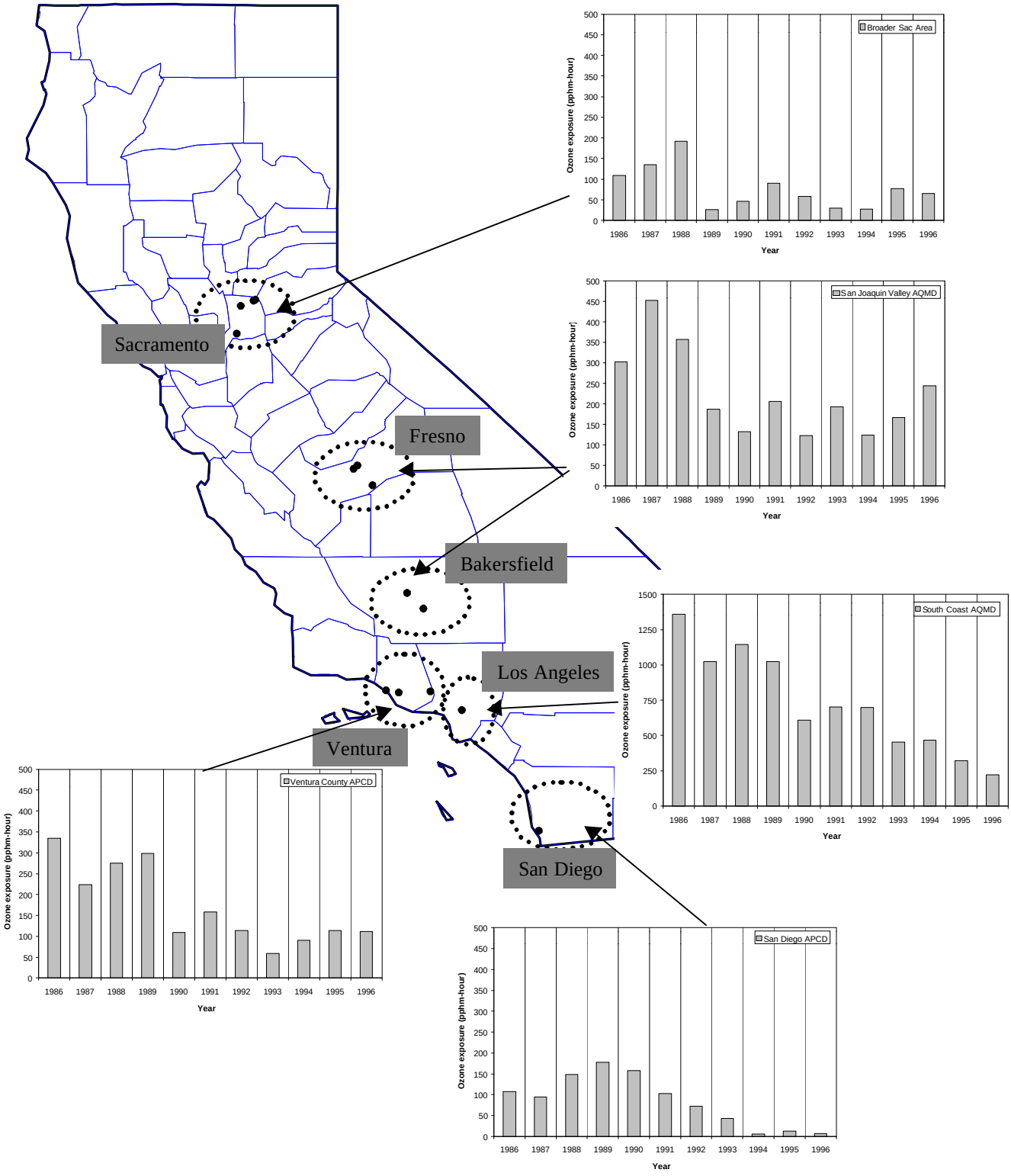

Figure 3-2. Cumulative ozone exposure by year for selected MSAs in California. Note the y-axis for the South Coast AQMD plot is three times greater than the y-axes for the other plots.

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4. SACRAMENTO TRENDS IN OZONE

4.1 OVERVIEW

The air quality at the PAMS Type 1 Elk-Grove-Bruceville, the PAMS Type 2 Del Paso Manor, and the PAMS Type 3 Folsom sites in Sacramento was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1–hr Ozone NAAQS were considered in the analyses. **Figure 4-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for the three sites from 1987 to 1997. **Figure 4-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for the three sites from 1987 to 1997. These figures illustrate that there was a general decline in the number of exceedances per year from 1987 to 1997.

The analyses involving exceedances of the 1-hr Ozone NAAQS at the Del Paso Manor site will be given special focus in this section; the analyses involving the California Ozone Standard and the Elk Grove-Bruceville and Folsom sites are presented in Appendix B.

Normally, the statistical and adjustment techniques are applied to PAMS Type 3 sites where maximum ozone concentrations are observed. However, the unavailability of complete temperature measurements at the Folsom site and the relocation of the Folsom site in 1996 limited its utility as a trending site. The Del Paso Manor site is classified as a PAMS Type 2 site where the greatest amounts of precursor emissions are released. The Del Paso Manor site presents several issues that are expected to impact the interpretation of trends in air quality at the site:

- Reporting units changed from pphm to ppb on December 31, 1994.
- Del Paso Manor temperature measurements were only available from 1996 to 1997.
- Sacramento Metro Airport NWS station temperature measurements were used to supplement Del Paso Manor temperature measurements from 1988 to 1995.
- NO_x and hydrocarbon measurements were only available from 1994 to 1997.

Several statistical analyses of the ozone air quality were performed for this site. The analysis uncertainty is used to interpret the trends. The ARB performed a statistical analysis of the total exposure hours for the broader Sacramento area; that analysis is also discussed in this section.

Adjustment techniques were applied to the Del Paso Manor site to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was expected that the variability would add an additional uncertainty to the trends analyses. Adjustment techniques that were performed by other researchers for the Del Paso Manor site (or a nearby site) are also discussed in order to investigate the uncertainty in the trends analysis as a function of their techniques. The findings of all the adjustment techniques are discussed in

terms of the statistical analyses (Section 4.2) in order to establish a consensus among the different analysis approaches.

4.2 STATISTICAL ANALYSES

The statistical analyses of the Del Paso Manor air quality revealed an improvement in the ozone air quality (i.e., a decrease in ozone concentrations) at the site from 1987 to 1997 as measured by the following indicators: the number of exceedance days dramatically decreased over the time period and the highest daily maximum ozone concentration decreased over the time period. The analyses also identified several years during which the air quality was dramatically improved (e.g., 1989, 1994, and 1997). Some statistics did not reveal clear trends and were also subject to large analysis uncertainties, including average exceedance concentration over the time period and 3-yr running average exceedance concentration over the time period. These findings suggest that anomalous atmospheric or meteorological events were responsible for the inconsistent changes in air quality.

4.2.1 Average exceedance concentration

Figure 4-3 shows the distribution of the daily maximum ozone concentrations from 1987 to 1997. Figure 4-3a shows that the bulk of the daily ozone concentrations (i.e., interquartile range) were at or below the California Ozone Standard criteria and that the median ozone concentrations exhibit a slightly decreasing trend over the entire time period at this site. Figure 4-3a also demonstrates that the bulk of the daily maximum ozone concentrations that occurred at the site in 1989, 1993, and 1997 were lower than average and that the bulk of the daily maximum ozone concentrations that occurred at this site in 1988 were higher than average. In Figures 4-3b and 4-3c, the presence of outlier points with smaller ranges in the bulk of the ozone concentrations suggests that high exceedance concentrations were less common and farther from the average in the 1990s. In 1997, there are fewer outlier points, and the daily ozone concentrations are closer to the concentration thresholds set by the California Ozone Standard and the 1-hr Ozone NAAQS. This suggests that a near compliance with the standards is more commonplace in later years. The lack of outlier points in the late 1980s in these figures suggests that exceedances were commonplace and closer to the high average concentrations experienced at the site.

Figure 4-4 shows the average exceedance concentrations at the Del Paso Manor site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in the Figure 4-3 are not distinguishable when the analysis uncertainties of the exceedance concentrations are considered. In 1989 and 1997, the annual average exceedance concentrations are not shown because there were no exceedances of the 1-hr Ozone NAAQS during these years. Further, there is no analysis uncertainty on the average exceedance concentration in 1994 because there was only a single exceedance of the standard.

4.2.2 Running 3-yr average of exceedance concentrations

The running 3-yr average concentrations of the 1-hr Ozone NAAQS exceedances are also shown in Figure 4-4. In 1989 and 1997 there were no exceedances of the 1-hr Ozone NAAQS at this site. In order to calculate the 3-yr average concentration statistic, each year in the average must have a nonzero value. As a result, this analysis would be limited to the time from 1990 to 1996. To extend the analysis over the complete time period, the highest ozone concentration in these two years (120 ppb in 1989 and 107 ppb in 1997) were used in lieu of exceedance concentrations.

Figure 4-4 illustrates that the average exceedance concentrations do not vary considerably over the entire time period when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period (i.e., 3-yr running average). Although the overall lack of variability in the 3-yr average exceedance concentration is consistent with the inability to infer trends when the analysis uncertainty was considered, this could also suggest that anomalous events (such as atypical meteorological events) are responsible for the variations in the average exceedance concentrations.

The lower daily maximum ozone concentrations experienced at the Del Paso Manor site in 1989 and 1993 are not prominent when this approach is taken. However, a notable decrease in the average concentrations in 1996 as a result of lower daily maximum ozone concentrations in 1997, is prominent. Lower daily maximum ozone concentrations, discernible even when they are distributed over a longer time period, suggest that the reduced average exceedance concentrations in 1997 are statistically significant.

4.2.3 Total number of exceedances of the standard

Although the average exceedance concentration did not dramatically change from the late 1980s to the late 1990s, the number of exceedance days have definitely decreased. **Figure 4-5** demonstrates this point. This figure also demonstrates that fewer exceedances and lower average exceedance concentrations occurred in 1989 and 1997. The majority of the exceedances were associated with exceedance concentrations between 125 and 140 ppb. Exceedance concentrations higher than 160 ppb were experienced only in 1991.

4.2.4 Identification of the highest exceedance concentrations

Figure 4-6 shows the top three exceedance concentrations experienced at the Del Paso Manor site. This figure illustrates that the highest exceedance concentrations were close to the average exceedance concentration during years with fewer exceedances and lower average exceedance concentrations (e.g., 1992). This figure also illustrates that the highest exceedance concentrations were much greater than the average exceedance concentration during years with more exceedances and higher average exceedance concentrations (e.g., 1991). This finding suggests that the years with fewer exceedances and lower average exceedance concentrations are more representative of typical (i.e., average) air quality at the Del Paso Manor site.

4.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated, no significant trend was observed. However, because it was possible that there were too few exceedances of the 1-hr Ozone Standard for this analysis to result in a statistically defensible trend, lower thresholds were also considered in this analysis. **Figure 4-7** illustrates that daily maximum ozone concentrations do not vary significantly by day of week even when lower thresholds are considered. This suggests that, statistically, there is no greater chance on any given day of exceedances of the 1-hr Ozone NAAQS.

4.2.6 Spatial distribution of exceedances

An overall improvement in the air quality at the Elk-Grove-Bruceville, Del Paso Manor, and Folsom sites was revealed from 1987 to 1997. Figure 4-2 illustrates that the number of exceedance days decreased, and the average concentration of the exceedances of the 1-hr Ozone NAAQS for the three sites remained stable or decreased slightly.

A comparison of the air quality at the three sites also revealed several interesting features:

- As expected, more exceedances and higher daily maximum ozone concentrations occurred at the PAMS Type 3 site than at the PAMS Type 2 or 1 sites.
- In general, the number of exceedances and average exceedance concentrations followed similar trends over time.
- The PAMS Type 2 and 3 sites experienced dramatically different ozone concentrations in 1989 and 1990. In 1989, the number of exceedances at the PAMS Type 2 site dropped dramatically while the number of exceedances at the PAMS Type 3 site remained high. In 1990, the opposite trend was observed; the number of exceedances at the PAMS Type 3 site dropped dramatically while the number of exceedances at the PAMS Type 2 site rose dramatically.
- The number of exceedances and daily maximum ozone concentrations increased at the PAMS Type 1 site from 1993 to 1996. Because ozone concentration measurements were only available for this site from 1993 to 1997, it is difficult to distinguish whether this increase is significant or is within the variations observed at the PAMS Type 2 and PAMS Type 3 sites.

Similar issues appear to influence the air quality at all three sites, and regional transport might be an issue for the downwind site. However, a comparison of trends in the exceedances at the sites should be regarded with caution because the Folsom site was relocated in 1996, and limited measurements were available for the Elk Grove-Bruceville site.

4.2.7 Number of exceedances of the standard by meteorology

Temperature measurements were only available from 1995 to 1996 for the Del Paso Manor site. However, excellent correlation between the Del Paso Manor and Sacramento Metro Airport measurements was demonstrated for these two years. As a result, the Del Paso Manor site temperature measurements were supplemented with measurements made at the NWS station at the Sacramento Metro Airport from 1988 to 1995. The subsequent analyses involving temperature measurements use this supplemented data set.

Figure 4-8 shows the distribution of the daily maximum temperatures from 1988 to 1997. The figure shows that the bulk (i.e., interquartile range) of the daily maximum temperatures on the exceedance days was approximately 5 to 20^{o}F higher than the average daily maximum summertime (May through October) temperature. This trend was fairly consistent over the entire time period. Figure 4-8 also demonstrates that the average daily maximum temperature was 5 to 10^{o}F higher on days that exceeded the 1-hr Ozone NAAQS (Figure 4-8c) than on days that only exceeded the California Ozone Standard (Figure 4-8b). This finding suggests that the meteorology (with temperature as an indicator of meteorology in general) was atypical of the average summertime meteorology at the Del Paso Manor site on exceedance days.

Figure 4-9 shows a bar graph of the number of days above the ozone standard and the number of days above 90^{o}F for 1987-1997 and a bar graph of the ratio of the number of days above the ozone standard and the number of days above 90^{o}F. The plots also show the annual average exceedance concentrations and 3-yr running averages of the exceedance concentrations. These plots demonstrate that there is no discernible relationship between the number of days above the 1-hr Ozone NAAQS and the number of days above 90^{o}F. Although all of the exceedances of the 1-hr Ozone NAAQS occurred on days with temperatures above 90^{o}F, this figure demonstrates that there were many days of elevated temperatures when exceedances did not occur. In fact, the number of exceedances decreased although the number of days that experienced temperatures above 90^{o}F increased during some years (e.g., 1992, 1994, 1997).

The ratio of the ozone exceedances and the days above 90^{o}F provides a sample method of adjusting the ozone air quality in a given year based on temperature influence. This ratio varies significantly by year with the ratio in 1997 much lower than in 1988.

4.2.8 Cumulative population-weighted exposure hours

Figure 4-10 shows an estimate of the cumulative population-weighted number of hours that the broader Sacramento area is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1998. This statistic consolidates into a single indicator the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances. This broader perspective on

air quality suggests that 1989, 1993 and 1994 experienced dramatic improvements in the air quality (in terms of ozone) in the broader Sacramento area, and not just at the Del Paso Manor site. The exposure calculations have not been compiled for 1997 yet. The analysis suggests that when a broader area is considered, the air quality in the broader Sacramento area has improved dramatically from the late 1980s to the late 1990s. This dramatic finding was obscured in prior analyses of the average exceedance concentration indicator. However, a statistical evaluation of the exposure-hours was not available to assess the analysis errors.

4.2.9 Exceedance concentrations as a function of early morning precursor concentrations

Figure 4-11 illustrates that the exceedance concentrations are not related to the average early morning NO_x and VOC precursor concentrations. This is true for both the average exceedance concentrations and the second highest daily maximum ozone concentration. The average ratios appear to be in the VOC limited regime, suggesting that reductions in VOC concentrations will result in lower maximum ozone concentrations. However, when the analysis uncertainty is also considered, the ratios span all three regimes of limitation (NO_x, VOC, and transitional). As a result, the suggested effect of VOC emission reductions is unclear based on this analysis alone.

4.3 ADJUSTMENT ANALYSES

Several of the statistics discussed in the previous section did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques discussed in this section are used to assess whether the uncertainty analysis is, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques are used to estimate the uncertainty in the ozone measurements as a result of atmospheric or meteorological variability from 1987 to 1997 and as a result of differences in meteorology from year to year. It is anticipated that the adjustment techniques will enable more clear trends to be determined.

4.3.1 EPDCs as a function of early morning precursor concentrations

EPDCs were determined for 1989 to 1997 using RECRATE (Air Resources Board, 1996). The EPDC is analogous to an annual second highest ozone concentration. However, it is a hypothetical concentration that is determined by smoothing the highest 20 percent of the daily maximum ozone concentrations. This adjustment technique minimizes the importance of some of the highest daily maximum ozone concentrations if these concentrations are atypical of the bulk of the highest ozone concentrations. This technique does not target atmospheric or meteorological variability specifically.

Figure 4-11 illustrates that the Del Paso Manor EPDCs follow a decreasing trend over the entire time period and experience a dramatic low in 1994. The EPDCs do not reveal dramatic decreases in 1989 and 1997 (as observed in some statistics in Section 4.2), suggesting

that the improvement in air quality at the Del Paso Manor site in 1989 and 1997 was the result of anomalous events that have been minimized by the smoothing process. However, it is interesting that the EPDC estimate for 1994 is clearly below the typical EPDCs because 1994 was not identified in prior analyses.

Figure 4-11 also illustrates that the EPDCs are not conclusively related to the average early morning NO_x and VOC precursor concentrations. The average ratios appear to be in the VOC limited regime, suggesting that reductions in VOC concentrations will result in lower maximum ozone concentrations. However, when the analysis uncertainty is also considered, the ratios span all three regimes of limitation (NO_x, VOC, and transitional). The EPDCs increased from 1994 to 1995. Over this same time period, the VOC to NO_x ratios also appeared to increase although the increase is questionable when the analysis uncertainty is considered. The EPDCs remained stable from 1996 to 1997. Over the same time period, the VOC to NO_x ratio also appeared to be stable. These trends are logical. However, the uncertainty on the precursor concentrations is large. Because precursor information was not available prior to 1994, this inconsistency with the other analyses cannot be explored.

4.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis as a result of atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this report, the concept of native variability was also applied to average daily maximum ozone concentrations. This will allow the uncertainties as a result of the analysis and the uncertainties as a result of atmospheric and meteorological variability to be directly compared.

Figure 4-12 demonstrates the native variability about the EPDC. When 95 percent confidence limits are associated with the native variability estimates, the most significant reduction in ozone concentrations since 1990 is seen in 1994. All other years do not demonstrate a substantial reduction in the EPDC (relative to 1990) when native variability is considered. This is interesting because the average exceedance concentration and 3-yr average exceedance concentration indicators did not identify 1994 in previous analyses. (The year 1994 was identified using the number of exceedance days indicator.) This would suggest that the improvement in air quality in 1994 was more dramatic than the natural variability in the daily maximum ozone concentrations. Therefore, the reduction in ozone concentration in 1994 is statistically viable although it was completely unnoticed in previous analyses. Similarly, this suggests that the reduced ozone concentrations that were observed in 1989, 1993, and 1997 are within the natural variability of the measurements and are not real improvements in ozone air quality. These findings are not consistent with trends developed in Section 4.2.

Figure 4-13 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS at the Del Paso Manor site. The trends suggested in this analysis are consistent with the analysis uncertainties that were discussed earlier. When 95 percent confidence limits are considered, the ozone concentrations exhibit a dramatic reduction in 1997

and a slight reduction in 1994. This suggests that the improvements in air quality in 1994 were real and were larger than the uncertainty due to the native variability of the average ozone concentration. This analysis also suggests that the average ozone concentrations were dramatically higher in 1991, 1995, and 1996 than they were in 1990. In prior analyses, only one year, 1991, was identified as having higher than average ozone concentrations. Finally, the improvement in air quality in 1994, that was suggested when the native variability of EPDC was considered, is no longer clear.

4.3.3 Meteorology adjustment using the Cox and Chu probability distribution technique

Figure 4-14 shows the maximum daily ozone concentrations that have been adjusted to account for meteorology with a confidence limit of 95 percent by Cox and Chu (1998). This figure suggests that meteorology had a dramatic effect on the observed ozone concentrations in the Sacramento MSA. This analysis was performed for a site, the specific location of which is unknown, in the Sacramento MSA. Because the maximum ozone concentrations presented in the Cox and Chu analysis are similar to the maximum ozone concentrations experienced at the Del Paso Manor site, the analysis was considered anyway. However, high ozone concentrations in 1991 and 1995 are not observed at the site that is the basis of this analysis, therefore, these findings should not be used to determine absolute concentrations for the adjusted ozone concentrations.

Figure 4-14 shows the actual maximum ozone concentrations, the modeled maximum ozone concentrations, and the adjusted maximum ozone concentrations. The modeled concentrations indicate how well the Wiebull distribution fit the daily maximum ozone concentrations. Note that in 1988, 1993, and 1996, the model did not capture the observed daily maximum ozone concentrations well. The adjusted concentrations are adjusted from the modeled concentrations. They represent the modeled concentration that would be likely if the temperature, wind speed, and wind direction conditions within a particular year were identical to the average meteorological conditions.

A gradually decreasing trend in the daily maximum ozone concentrations is clearer after adjustment. The overall decrease in the adjusted maximum annual ozone concentrations was approximately 13 percent between 1987 and 1997. This decrease is much smaller than the overall decrease that would be determined from the observed maximum annual ozone concentrations (closer to 28 percent). High ozone concentrations are lowered (e.g., 1988, 1990, and 1996), and low ozone concentrations are raised (e.g., 1989, 1992, and 1997) using this smoothing technique. These findings make sense, as meteorology can have positive and negative effects on ozone formation. Finally, it is expected that the Cox and Chu method will bias against both high and low ozone concentrations that do not fit well to the probability distribution. This is demonstrated in 1988, 1993, and 1996 when the modeled ozone concentrations are dramatically different from the actual (i.e., observed) ozone concentrations.

4.3.4 Meteorology adjustment using the Rao and Zurbenko filtering technique

At our request, the Kolmorov-Zurbenko filtering technique was applied to the Del Paso Manor daily maximum ozone concentrations by a coworker of Dr. Rao, Steven Porter. **Figure 4-15** presents Mr. Porter's results for the maximum daily ozone concentrations that have been separated into two time scales of ozone variability and adjusted to filter out the effects of temperature (personal communication with Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999). Surface temperature was the sole surrogate for meteorology in this analysis. The adjusted ozone concentrations reveal a gradually decreasing trend that is due to other long-term meteorological parameters (besides temperature) or policy and economic changes that have caused emissions changes in the Sacramento MSA.

Figure 4-15a illustrates that seasonal variability in temperature had a dramatic impact on the observed ozone concentrations (i.e., nearly 60 percent of the ozone concentrations are explained by the normal seasonal variations in meteorology). However, 40 percent of the seasonal ozone concentrations is not explained by temperature. This indicates that other meteorological parameters not used in this analysis are important to ozone formation in the Sacramento MSA. Some other possible parameters include latitude, longitude, elevation, station pressure, aerosol optical depth coefficients, terrain factors, monthly vertical ozone column depth, monthly albedo factor, total cloud cover, total opaque cloud cover, and precipitable water vapor.

Figure 4-15b illustrates that the long-term reduction in ozone concentrations was not substantially influenced by temperature; only 3 percent of the variability in ozone concentrations was explained by temperature. This finding suggests that some other atmospheric event was responsible for the variability in ozone concentrations on this time scale, such as variability in different meteorological parameters, emissions, or economic factors. Meteorological parameters, besides temperature, are likely to influence the long-term ozone formation at the Del Paso Manor site. Other meteorological parameters, besides temperature, are known to influence the seasonal ozone formation at this site. However, this analysis does reveal a clear downward trend in long-term ozone concentrations although it is unclear how to interpret the findings in the context of analysis uncertainty.

4.4 SUMMARY OF SACRAMENTO AIR QUALITY TRENDS

Table 4-1 summarizes the findings from statistical and adjustment analyses performed on data from the Sacramento area. The consensus is that ozone concentrations have generally declined between 1987 and 1997 at the Del Paso Manor site. (Similar trends in air quality were observed at the Elk Grove-Bruceville and Folsom sites.) Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability was found to obscure trends.

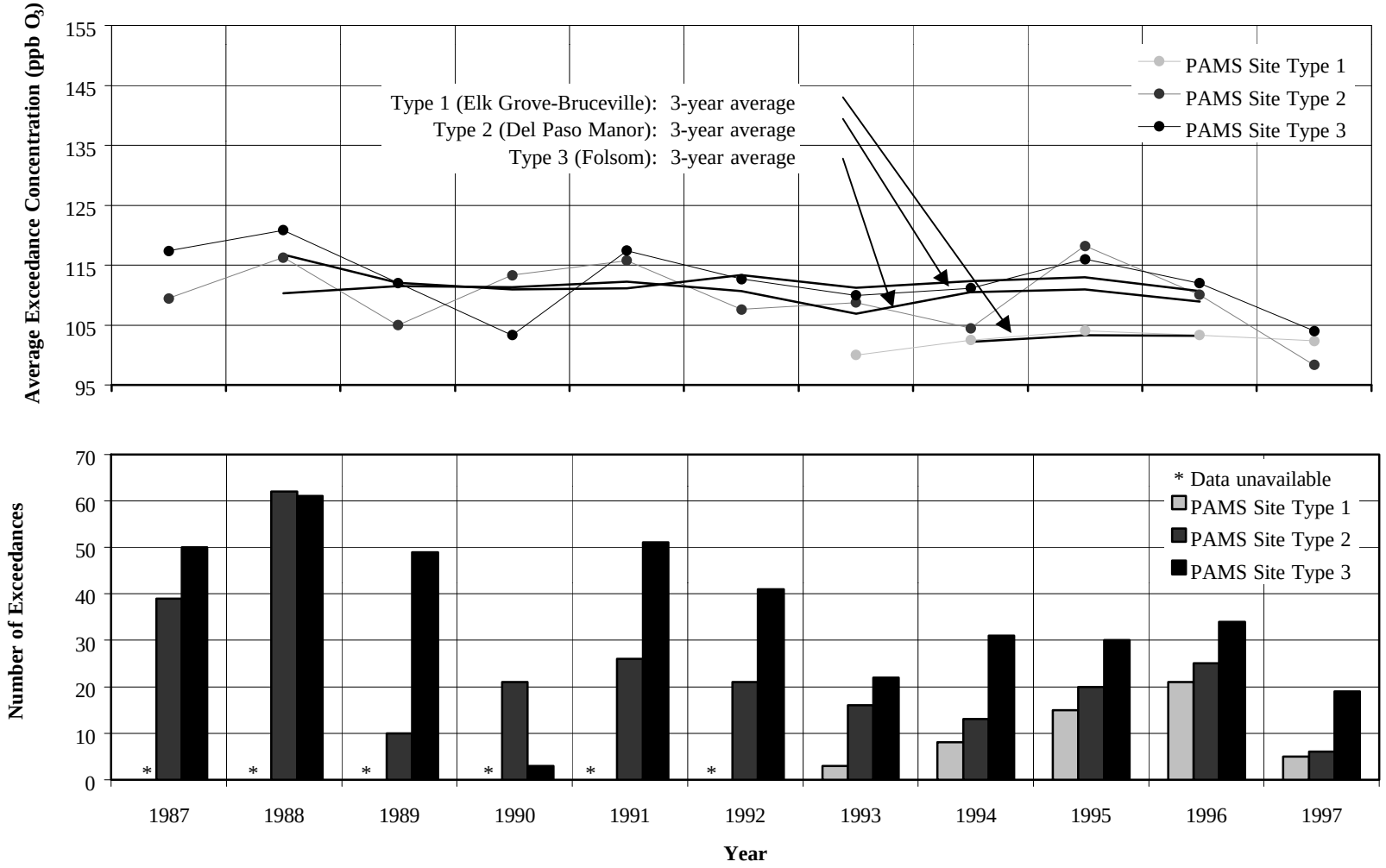

Figure 4-1. Exceedances of the California Ozone Standard at selected sites in the Sacramento MSA.

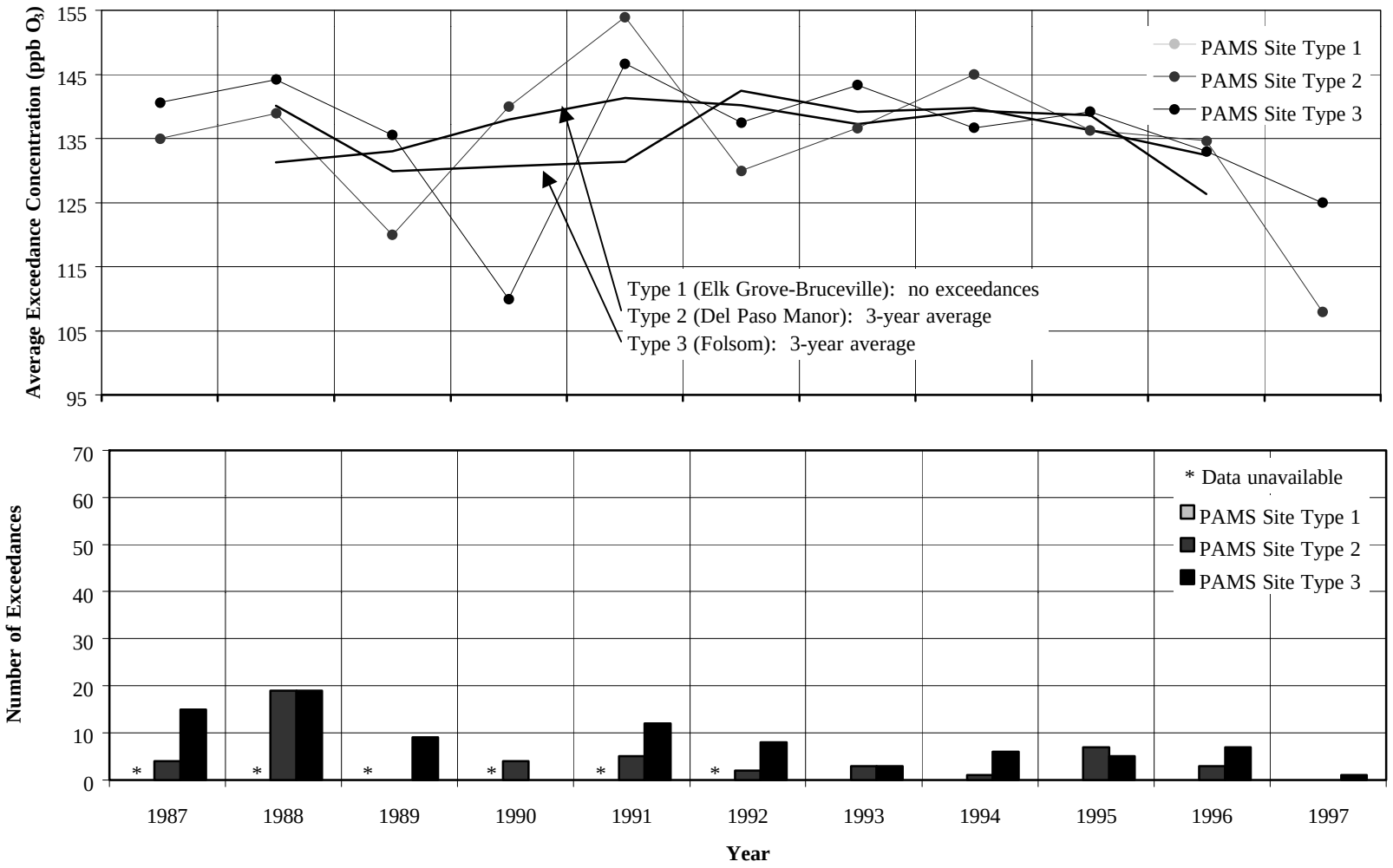

Figure 4-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the Sacramento MSA.

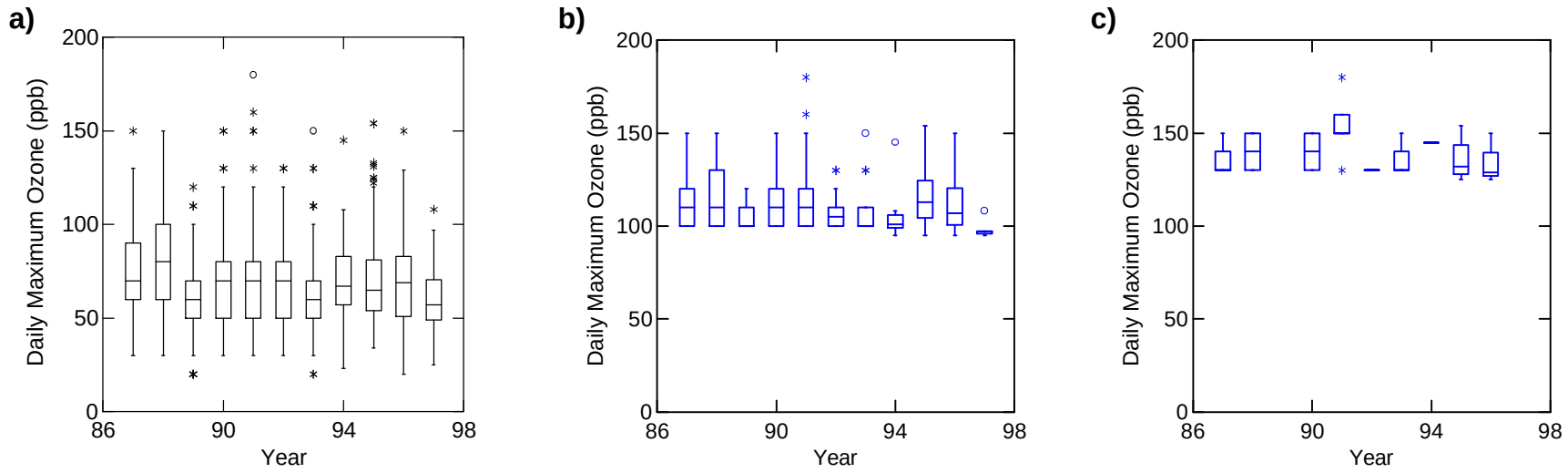

Figure 4-3. Daily maximum ozone concentrations for the Del Paso Manor site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

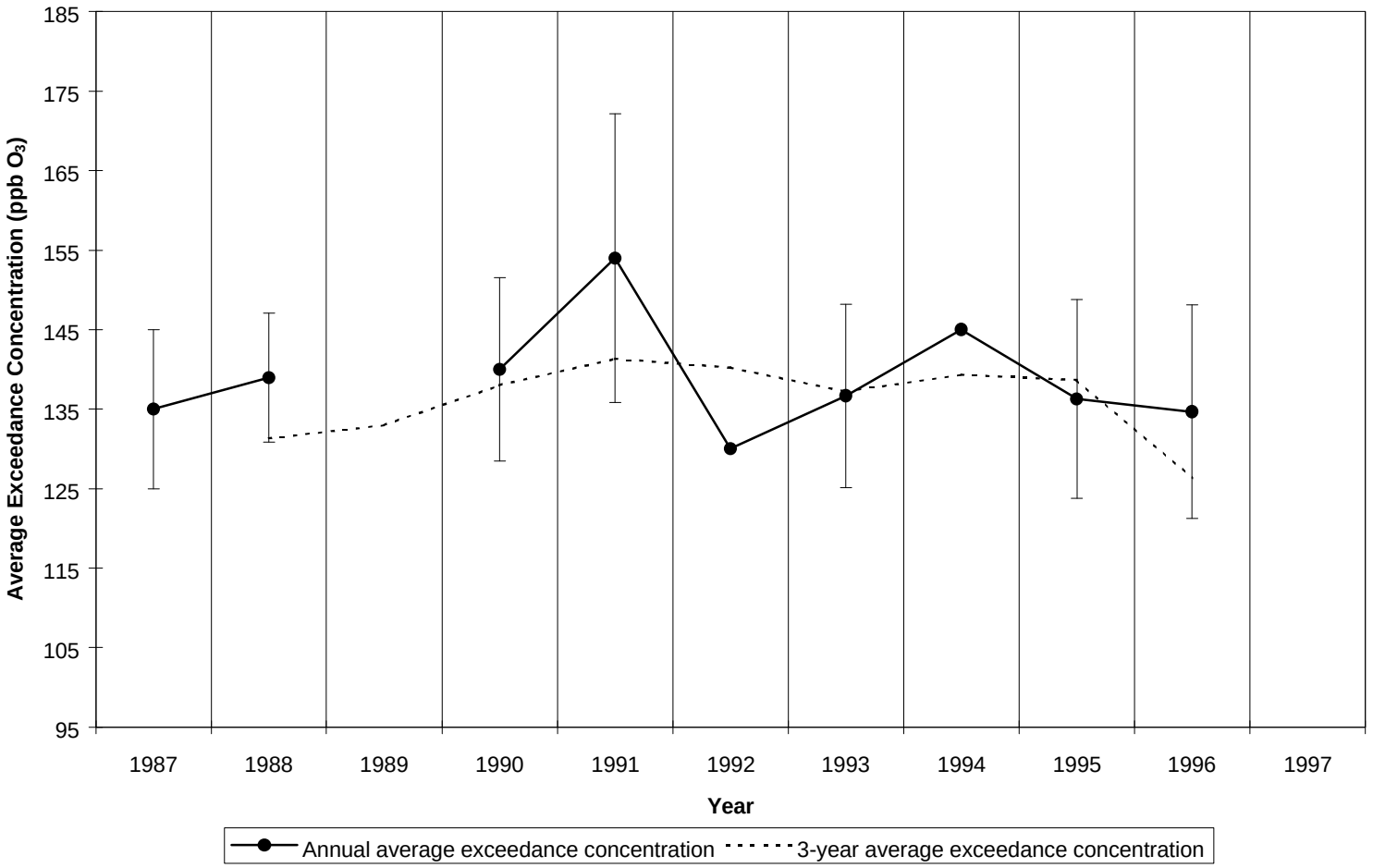

Figure 4-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty for the Del Paso Manor site. Three-year averages were determined using the highest non-exceedance ozone concentrations in 1989 and 1997 (years in which the 1-hr Ozone NAAQS threshold concentration was not reached). Error bars indicate the analysis uncertainty on the average ozone concentrations.

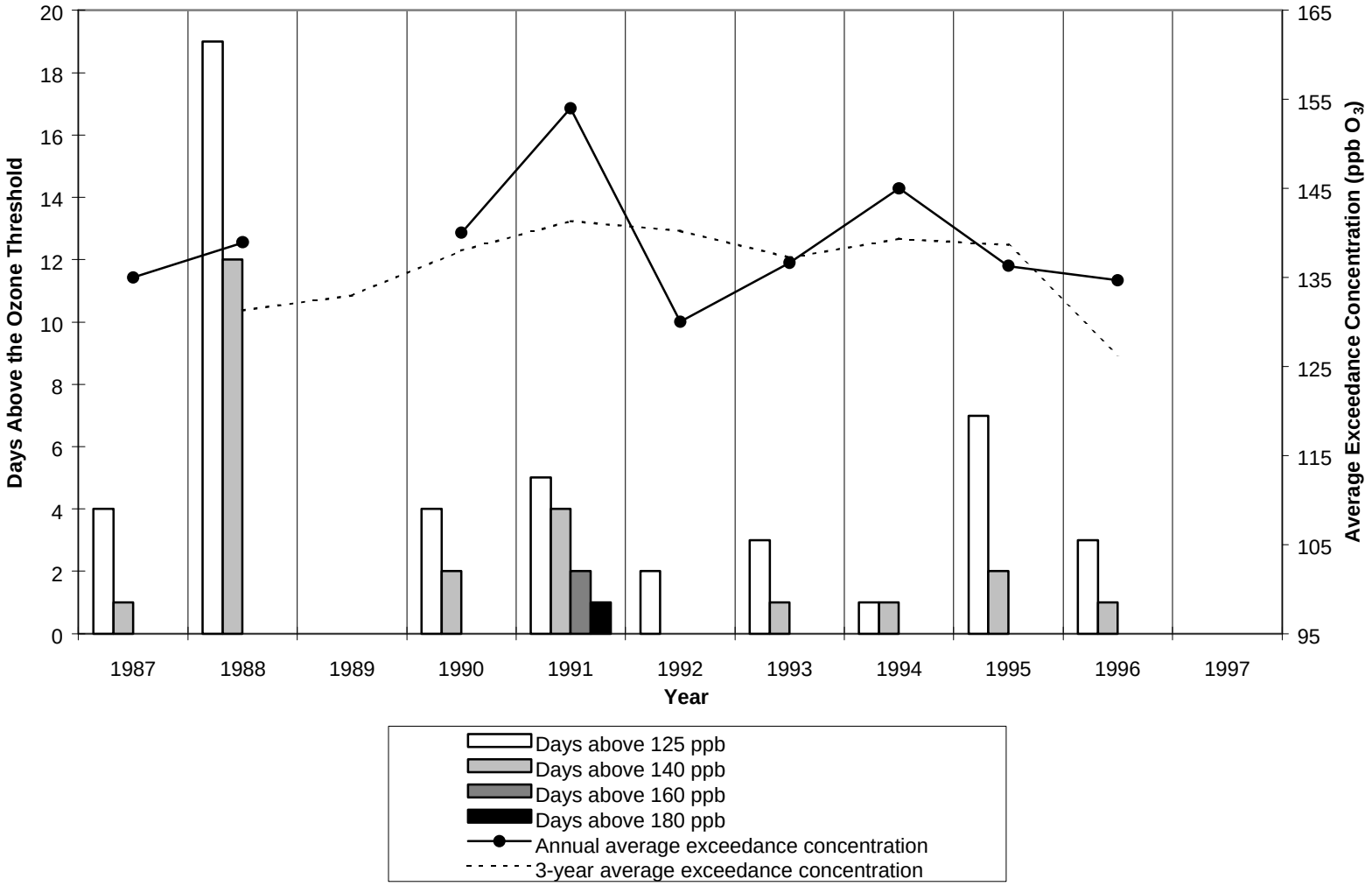

Figure 4-5. Total number of exceedances of the 1-hr Ozone NAAQS the Del Paso Manor site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

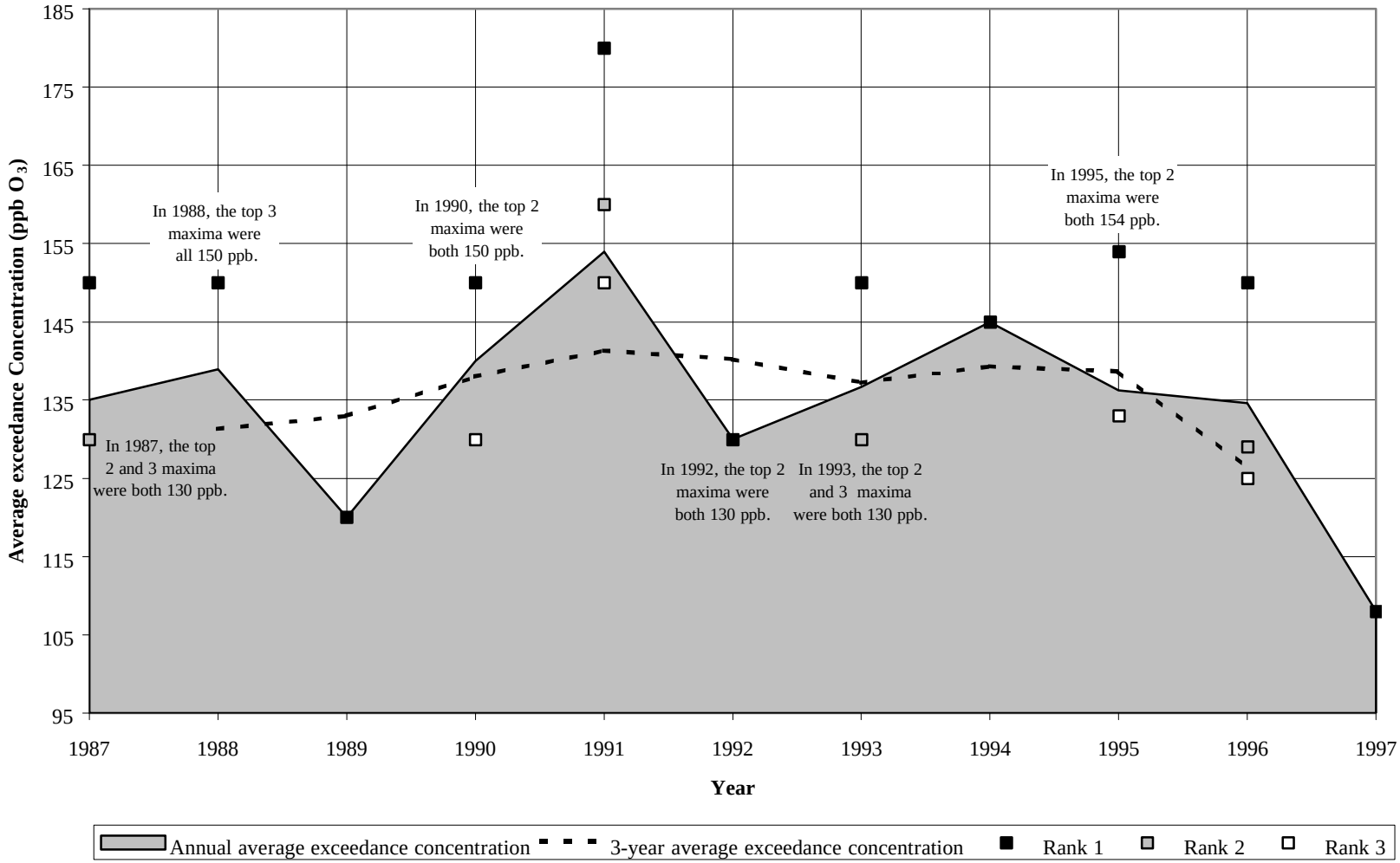

Figure 4-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS for the Del Paso Manor site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

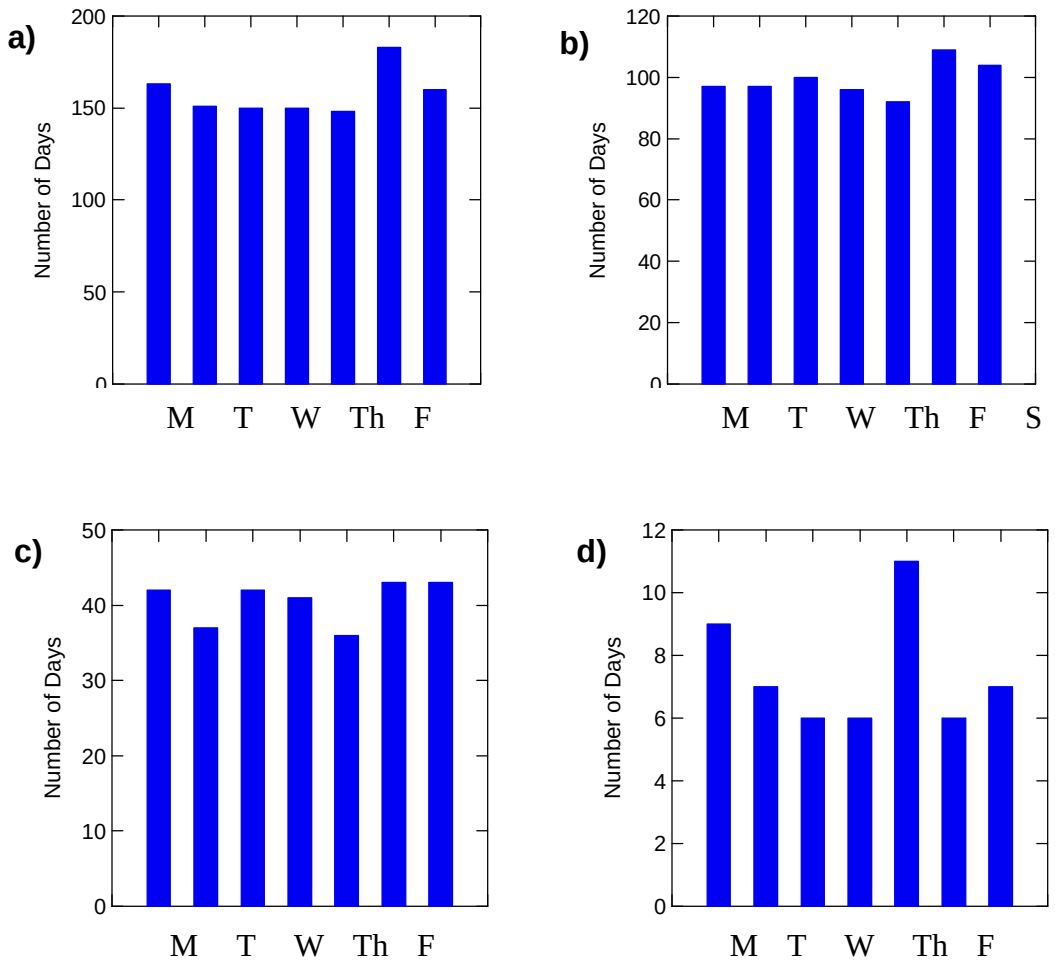

Figure 4-7. Number of days above a threshold ozone concentration by day of week for the Del Paso Manor site from 1987 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

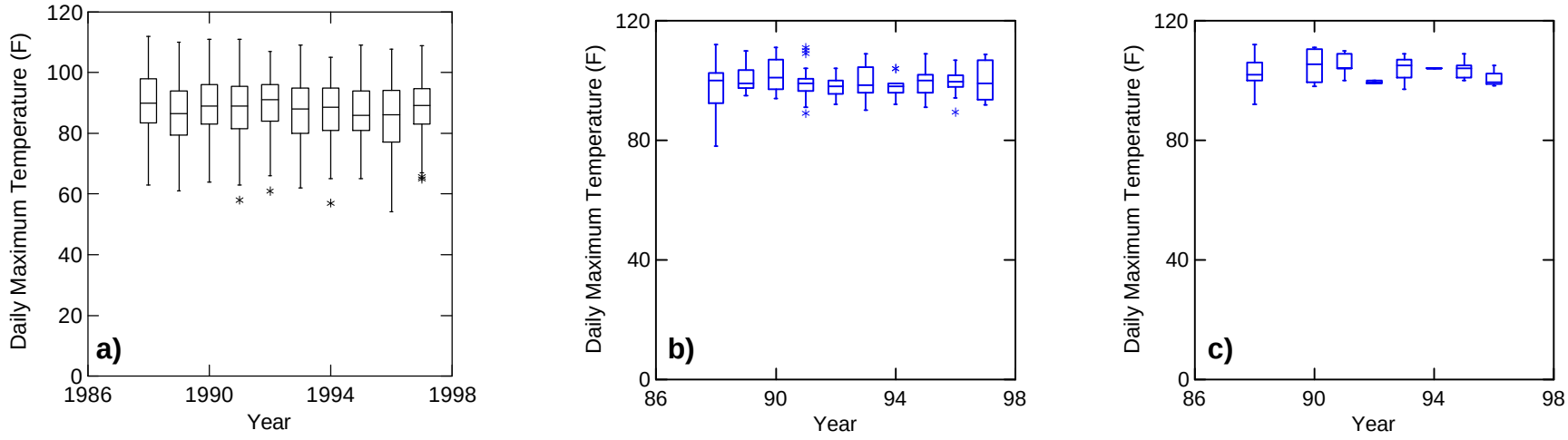

Figure 4-8. Daily maximum temperature for the Del Paso Manor site: a) all daily maximum temperatures, b) daily maximum temperature on days when the daily maximum ozone concentrations were above the California Ozone Standard, and c) daily maximum temperature on days when the daily maximum ozone concentrations were above the 1-hr Ozone NAAQS.

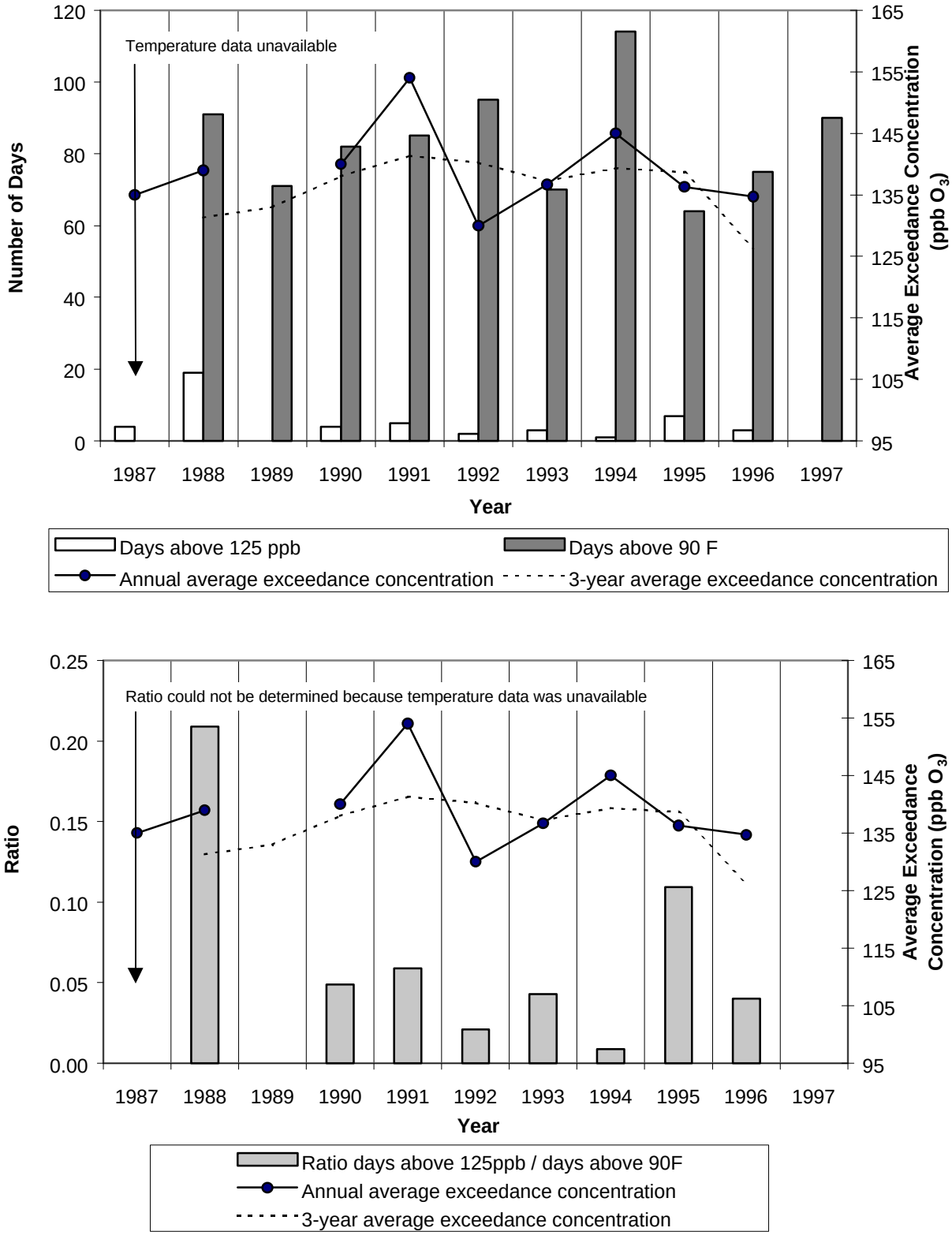

Figure 4-9. Number and ratio of the exceedances of the 1-hr Ozone NAAQS by meteorology for the Del Paso Manor site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

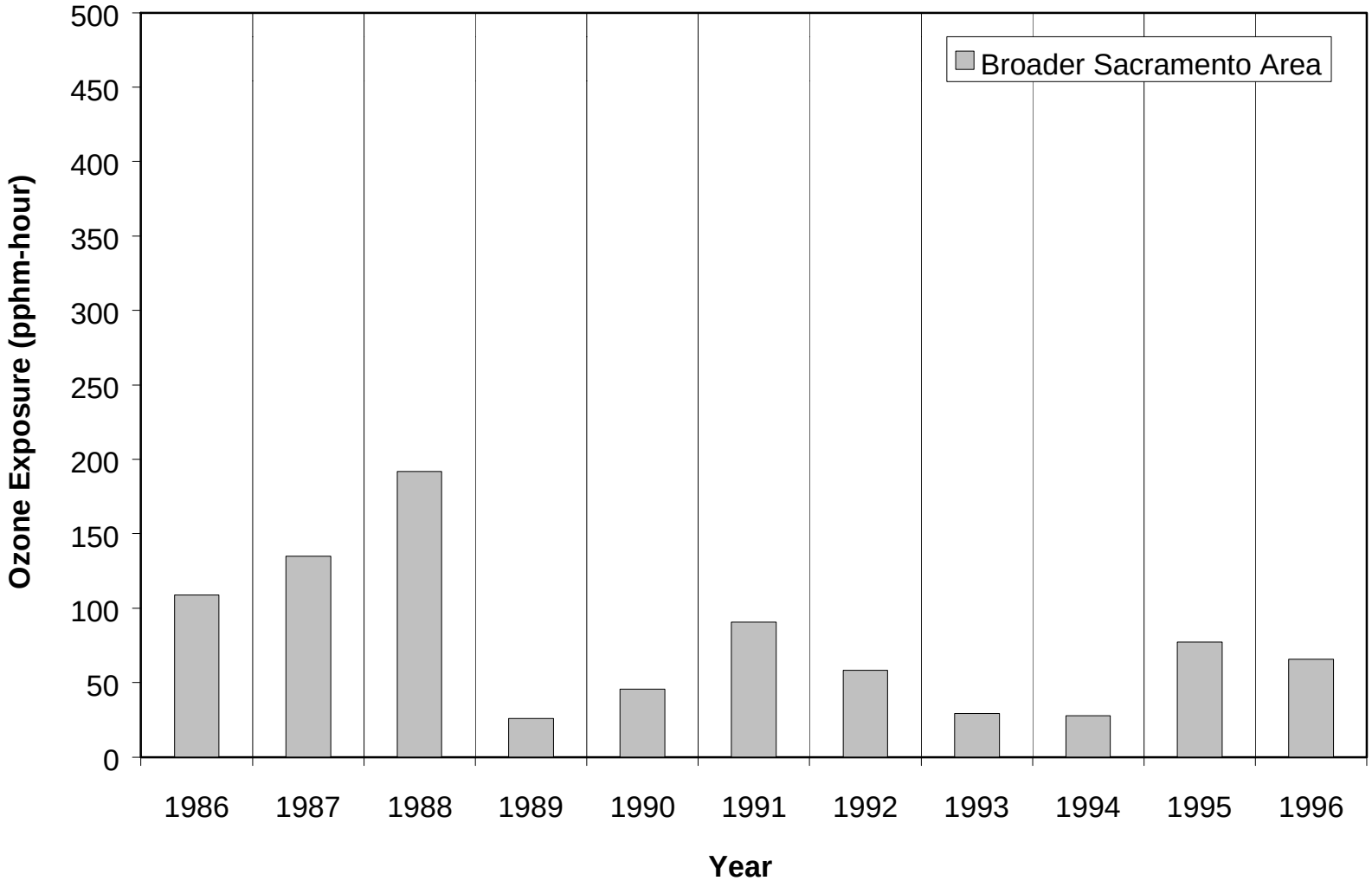

Figure 4-10. Cumulative population-weighted exposure hours of the broader Sacramento area to exceedances of the California Ozone Standard.

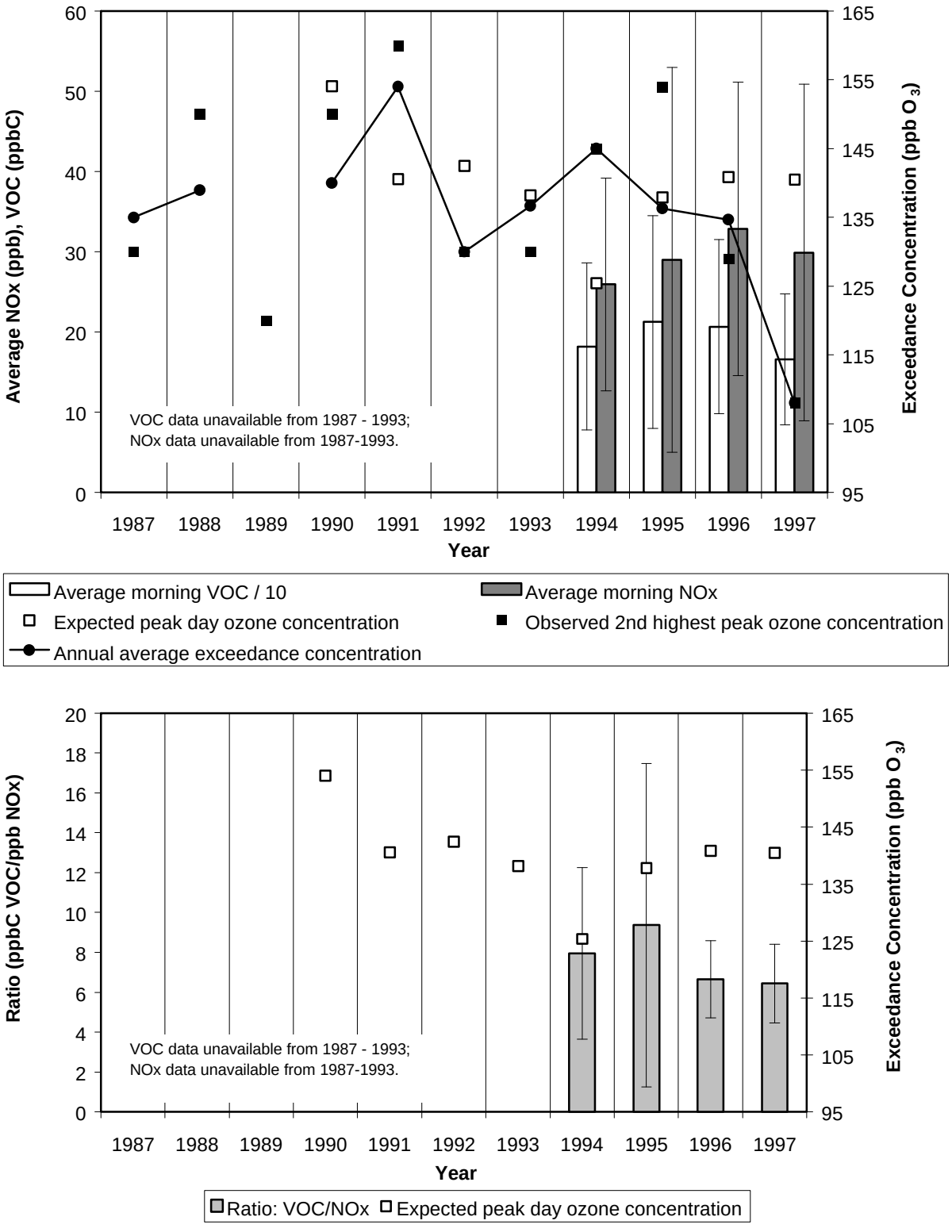

Figure 4-11. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the Del Paso Manor site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

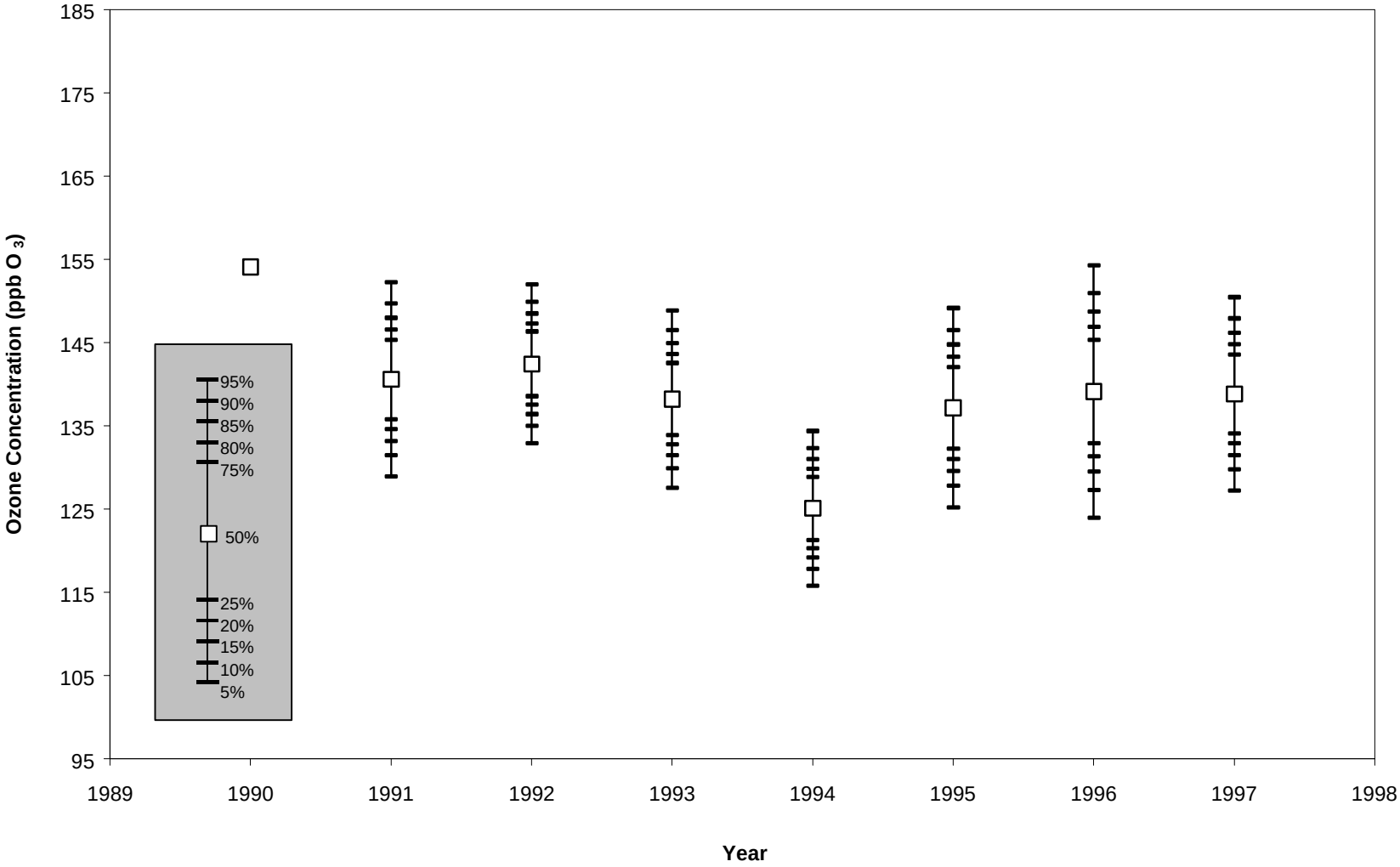

Figure 4-12. Variability of the EPDCs using native variability techniques for the Del Paso Manor site.

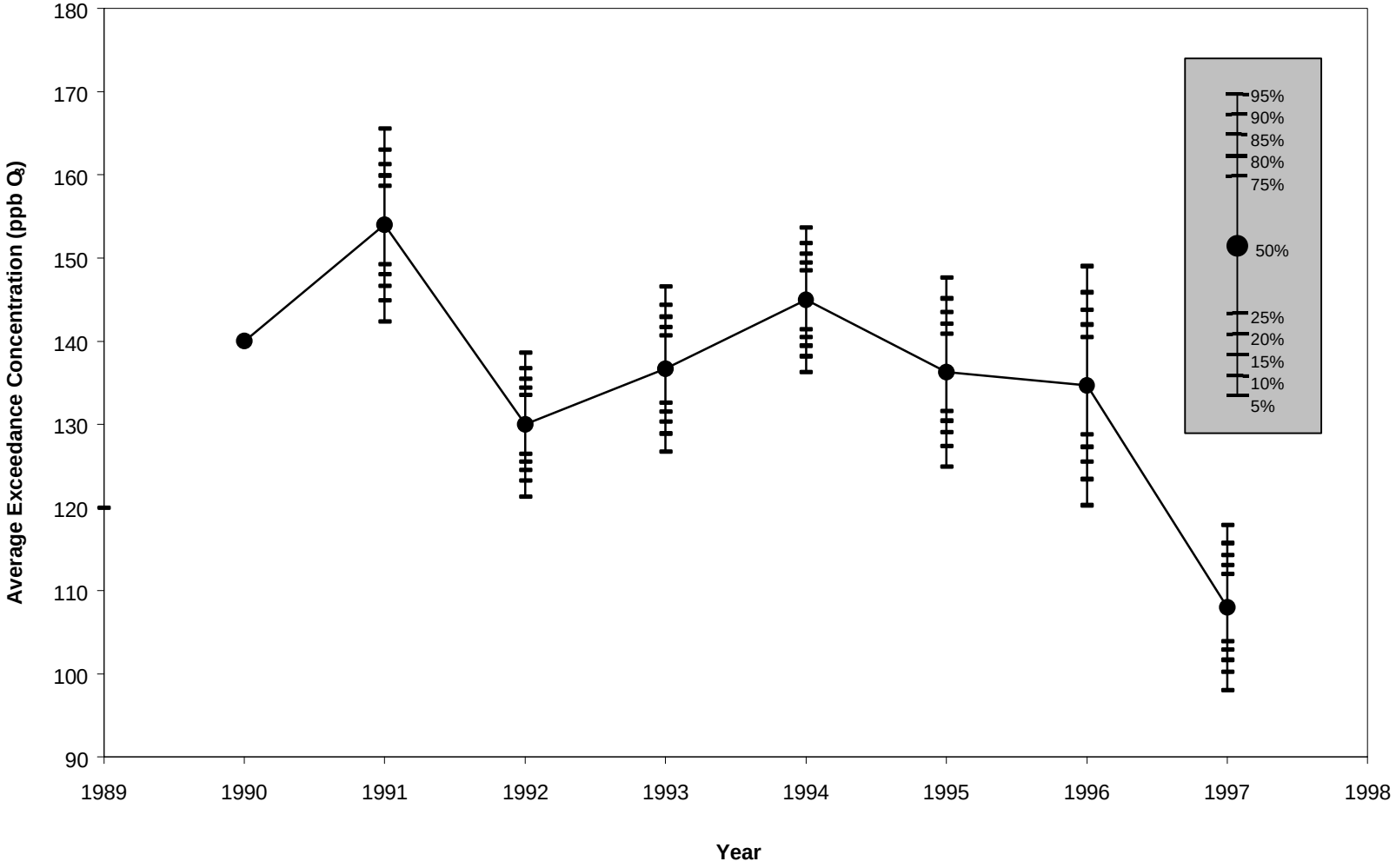

Figure 4-13. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the Del Paso Manor site.

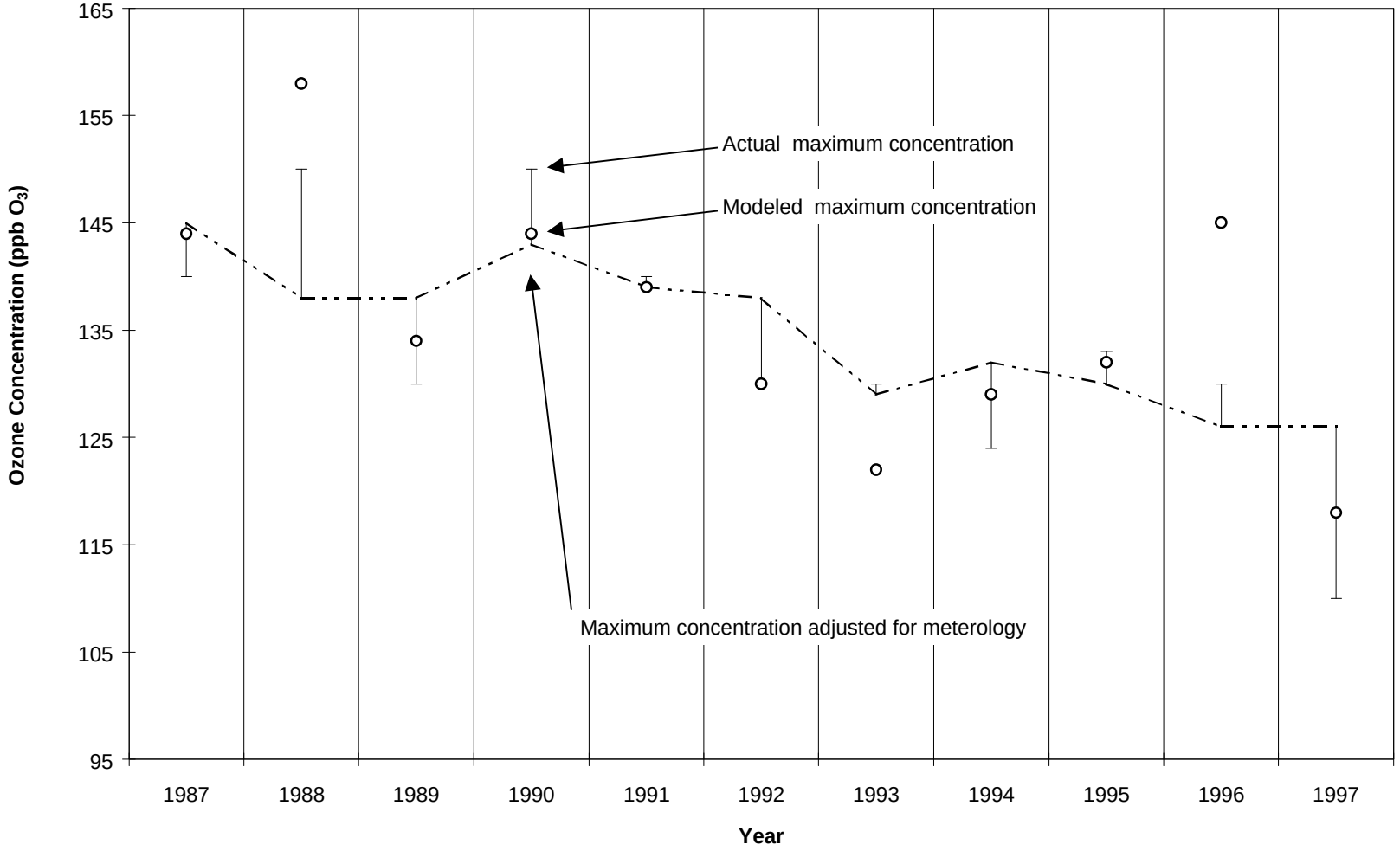

Figure 4-14. Meteorology adjustment of the maximum ozone concentrations using the Cox and Chu probability distribution techniques for a site in the Sacramento MSA.

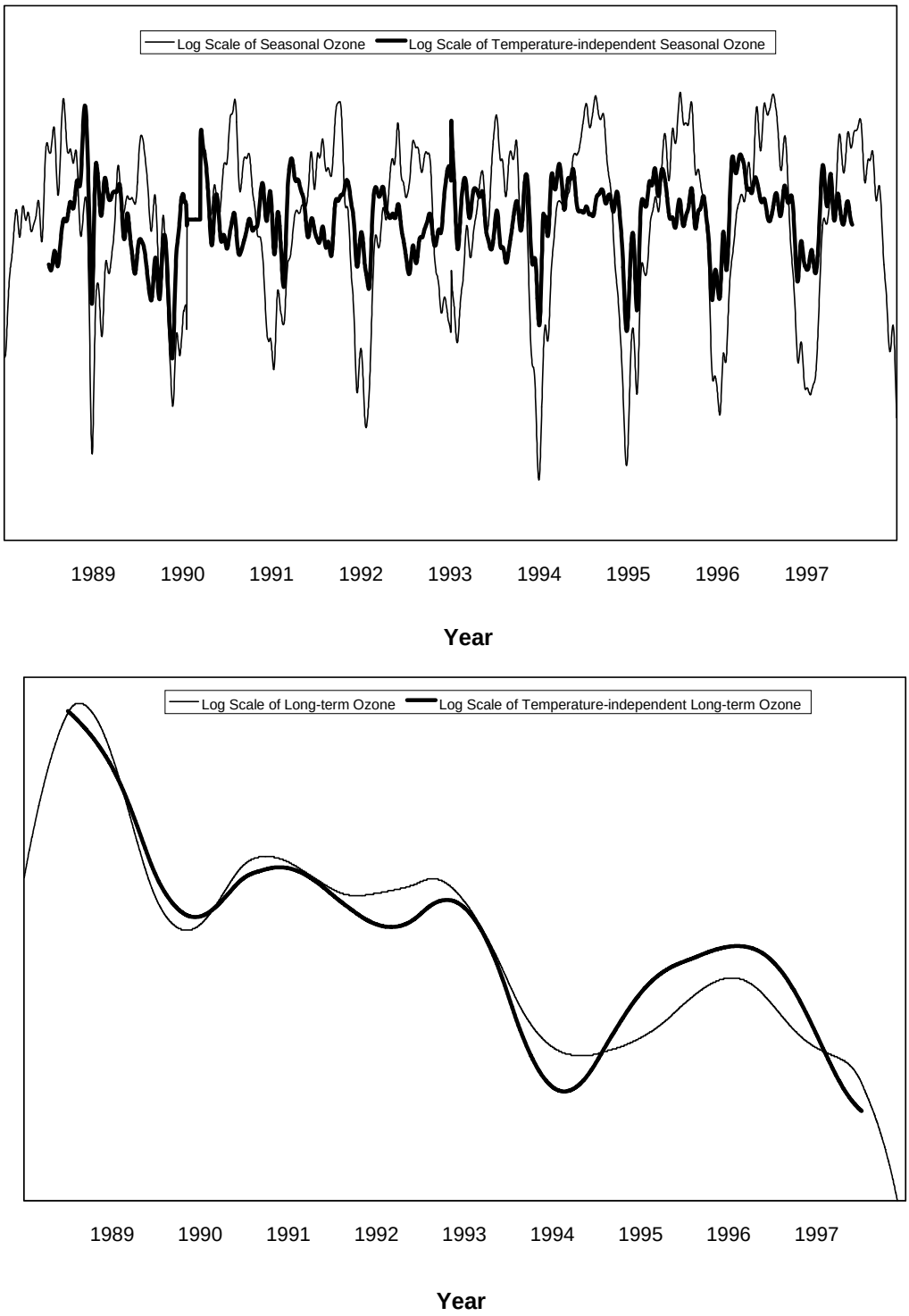

Figure 4-15. Meteorology adjustment of Del Paso Manor ozone concentrations using the Rao and Zurbenko filtering technique: a) seasonal component of ozone concentrations and b) long-term component of ozone concentrations (Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999).

Table 4-1. Summary of statistical and adjustment analyses performed on Sacramento area data.

Statistical Analyses	Trend in 1987-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward Inconclusive
Running 3-yr average of exceedance concentration	Inconclusive
Total number of exceedances	Downward
Spatial distribution of exceedances	Consistent, downward
Maximum concentrations	Downward/inconclusive
Number of exceedances by meteorology	Downward/inconclusive
Cumulative population-weighted exposure hours	Downward
Morning precursor concentrations	Inconclusive
Morning VOC/NO_x ratios	Inconclusive
Adjustment Analyses	**Trend in 1987-1997 Ozone**
Expected peak day concentrations	Downward
Native variability of average daily maximum ozone concentrations	Inconclusive
Native variability of average exceedance concentrations	Downward/Inconclusive
Meteorological adjustment using probability distribution (Cox and Chu)	Downward
Meteorological adjustment using filtering techniques (Rao and Zurbenko)	Downward

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5. BAKERSFIELD TRENDS IN OZONE

5.1 OVERVIEW

The air quality at the PAMS Type 1/3 Arvin and PAMS Type 2 Golden State Avenue sites in the Bakersfield MSA was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1–hr Ozone NAAQS were considered in the analyses. **Figure 5-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for both sites from 1989 to 1997. **Figure 5-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for both sites from 1989 to 1997. These figures illustrate that there was a possible decline in the number of exceedances per year from 1989 to 1997 (heavily weighted by the lower concentrations in 1997).

The analyses involving exceedances of the 1-hr Ozone NAAQS at the Arvin site is given special focus in this section; the analyses involving the California Ozone Standard and the Golden State Avenue site are presented in Appendix C.

The Arvin site is classified as a PAMS Type 1/3 site. This site acts as both an upwind and downwind site for Bakersfield. Arvin is the focus of this discussion because of its designation as a maximum ozone concentration site. The Arvin site presents several possible issues that could affect an analysis of trends:

- Reporting units changed from pphm to ppb on December 12, 1993.
- Arvin ozone measurements were incomplete in 1989.
- Arvin temperature measurements were unavailable from 1989 to 1990 and in 1994. Arvin temperature measurements were incomplete in 1997.
- Bakersfield Airport NWS station temperature measurements were used to supplement the Arvin measurements from 1989 to 1995.

The Golden State Avenue site is classified as a PAMS Type 2 site. This site will be discussed to learn about the influence of emissions on the observed ozone concentrations. This site presents the following issues that could affect trends:

- Golden State Avenue ozone measurements were only available from 1994 through 1997.
- NO_x and hydrocarbon measurements were only available from 1994 through 1997.

Several statistical analyses of the ozone air quality at these sites were performed; a discussion of these analyses follows in this section. The analysis uncertainty is used to interpret the trends. The ARB performed a statistical analysis of the total exposure hours for the broader San Joaquin Valley air basin; that analysis is also discussed in this section.

Adjustment techniques were applied to the Arvin site to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was

expected that the variability would add an additional uncertainty to the trend analyses. Adjustment techniques performed by other researchers for the Arvin site (or a nearby site) are discussed in this section to investigate the uncertainty in the trends analysis as a function of their techniques. The findings of all the adjustment techniques are discussed in terms of the statistical analyses (Section 5.2) to establish a consensus among the different analysis approaches.

5.2 STATISTICAL ANALYSES

The statistical analyses of the Arvin site air quality revealed a minimal improvement in the ozone air quality at the site from 1989 to 1997 as measured by the following indicators: the number of exceedance days and the highest daily maximum ozone concentration decreased over the time period. The analyses also identified 1997 to be a year during which ozone concentrations and the number of exceedances were dramatically lower at the Arvin site than during previous years. Some statistics did not reveal clear trends and were also subject to large analysis uncertainties, including the average exceedance concentration over the time period and 3-yr running average exceedance concentration over the time period. The analysis of average ozone concentrations and precursor concentrations at the PAMS Type 2 Golden State Avenue site revealed a slight reduction in daily maximum ozone concentrations as a result of decreased precursor concentrations over the period.

5.2.1 Average exceedance concentration

Figure 5-3 shows the distribution of the daily maximum ozone concentrations at Arvin from 1989 to 1997. Figure 5-3a shows that the bulk of the daily ozone concentrations (i.e., interquartile range) were above the California Ozone Standard threshold concentration. The median ozone concentrations stay about the same over the entire time period. The bulk of the daily maximum ozone concentrations experienced at the site in 1997 were lower than average. Also, many of the daily maximum ozone concentrations experienced at this site in 1989 and 1996 were higher than average. Figure 5-3b demonstrates that when the exceedances of the California Ozone Standard are considered, daily maximum ozone concentrations in 1997 do not necessarily stand out. In Figure 5-3c, the presence of outlier points, but smaller ranges in the bulk of the ozone concentrations in 1993 through 1996, suggests that high exceedance concentrations were less common and farther from the average. In 1997, the daily ozone concentrations are closer to the concentration thresholds set by the California Ozone Standard and the 1-hr Ozone NAAQS and, thus, there are fewer outlier points. This suggests that near compliance with the standards is more commonplace in later years. The lack of outlier points in the late 1980s in these figures suggests that exceedances were commonplace and closer to the high average concentrations experienced at the site.

Figure 5-4 shows the average exceedance concentrations at the Arvin site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in the previous figure are not distinguishable when the analysis uncertainty of the exceedance concentrations is

considered. However, a slight reduction in the average concentration of the exceedances of the 1-hr Ozone NAAQS is observable in 1997. This decline in concentration in 1997 is inconsistent for the site and is typical for many of the other selected PAMS sites in California.

5.2.2 Running 3-yr average of exceedance concentrations

Figure 5-4 shows the running 3-yr average concentrations of the 1-hr Ozone NAAQS exceedances. The figure illustrates that the average exceedance concentrations gradually decline over the entire time period when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period. However, the decreasing ozone concentrations are within the magnitude of the analysis uncertainty (i.e., standard deviation of the average exceedance concentrations). Therefore, decreases in the ozone concentrations are inconclusive. This is consistent with the level distribution of the bulk ozone concentrations that were observed in Figure 5-3. The overall lack of variability in the 3-yr average exceedance concentration, consistent with the inability to draw trends when the analysis uncertainty was considered, could also suggest that anomalous events (such as atypical meteorological events) are responsible for the variations in the average exceedance concentrations.

5.2.3 Total number of exceedances of the standard

Although the average exceedance concentration was not observed to dramatically change from the late 1980s to the late 1990s, the number of exceedance days has definitely decreased. **Figure 5-5** demonstrates this point. The figure also demonstrates that the number of exceedance days associated with daily maximum ozone concentrations above 140 ppb decreased from 1989 to 1997. Exceedance concentrations above 160 ppb were uncommon after 1991, and exceedance concentrations above 180 ppb occurred only in 1989.

Figure 5-5 also demonstrates that an uncommonly large number of exceedances of the 1-hr Ozone NAAQS occurred in 1996 in addition to higher average exceedance concentrations. An uncommonly small number of exceedances of the 1-hr Ozone NAAQS were experienced in 1992 and 1997 in addition to the lower average exceedance concentrations. The year 1992 was not identified in prior analyses.

5.2.4 Identification of the highest exceedance concentrations

Figure 5-6 shows the top three exceedance concentrations experienced at the Arvin site. This figure illustrates that the highest daily maximum ozone concentration each year has decreased from 1989 to 1997. This figure also demonstrates that the highest exceedance concentrations were closer to the average exceedance concentration during the years with fewer exceedances (e.g., 1991 to 1995 and 1997). The highest exceedance concentrations were much greater than the average exceedance concentrations during years with more exceedances and higher average exceedance concentrations (e.g., 1989, 1991, and 1996).

This suggests that the years with fewer exceedances and lower exceedance concentrations are more representative of typical (i.e., average) air quality at the Arvin site in the 1990s.

5.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated, no trend was observed except for exceedances of the 1-hr NAAQS. An argument could be made that fewer exceedances of the 1-hr NAAQS occur on Sundays than on other days. However, **Figure 5-7** illustrates that daily maximum ozone concentrations do not significantly vary by day of week when lower thresholds are considered. This analysis suggests that, statistically, there is no greater chance on any given day of exceedances of the 1-hr California Ozone Standard.

5.2.6 Spatial distribution of exceedances

Figure 5-2 illustrates that, from 1989 to 1997, the number of exceedance days decreased at the Golden State Avenue and Arvin sites while the average concentration of the exceedances of the 1-hr Ozone NAAQS for both sites remained unchanged or decreased slightly. The exclusion of 1997 data from an analysis would lead to a flat or increasing trend.

A comparison of the air quality at the two sites also revealed the following interesting features:

- As expected, more exceedances and higher daily maximum ozone concentrations occurred at the PAMS Type 1/3 site (i.e., Arvin) than at the PAMS Type 2 Golden State Avenue site.
- In general, both sites experienced similar trends over time. Both of the sites experienced an increase in the number of exceedances and average exceedance concentrations from 1994 to 1996. Both sites also experienced a sharp reduction in the number of exceedances and average exceedance concentrations in 1997. However, ozone concentrations were only available for the Golden State Avenue site from 1994 to 1997; therefore, it is difficult to distinguish whether the changes from 1994 to 1996 are significant and consistent with the variations observed at the Arvin site from 1989 to 1997.

Similar issues appear to influence the air quality at both sites during the years for which concurrent ozone measurements are available. This suggests that regional transport is an issue for the Bakersfield MSA. However, a comparison of trends in the exceedances at the sites should be regarded with caution because limited measurements were available for the Golden State Avenue site.

5.2.7 Number of exceedances of the standard by meteorology

Temperature measurements were made at the Arvin site in 1991, 1992, and from 1995 to 1997. In 1997, these measurements were incomplete. Because the temperature measurements were discontinuous and did not span the time period for which ozone measurements were available, Arvin site temperature measurements were supplemented with measurements made at the NWS station at the Bakersfield Airport from 1989 to 1995. The temperature measurements at the Arvin site and the Bakersfield Airport NWS station demonstrated excellent correlation for the years of concurrent temperature measurements. The correlation plot is presented in Appendix A. The subsequent analyses involving temperature measurements use the supplemented data set.

Figure 5-8 shows the distribution of the daily maximum temperatures at the Arvin site from 1989 to 1997. The figure shows that the bulk of the daily maximum temperatures (i.e., interquartile range) on the California Ozone Standard exceedance days were not statistically different among the years or from all days. The median and bulk daily maximum temperatures on the 1-hr Ozone NAAQS exceedance days were 5 to 20^{o}F higher than the average daily maximum summertime (May through October) temperatures. This trend was fairly consistent over the entire time period. This suggests that the meteorology (with temperature as an indicator of meteorology in general) was atypical of the average summertime meteorology at the Arvin site on days with 1-hr Ozone NAAQS exceedances. Surprisingly, Figures 5-8b and 5-8c also demonstrate that the increased number of exceedances and average exceedance concentrations in 1996 was associated with lower daily maximum temperatures. However, the bulk of the temperatures in 1996 were still above 90^{o}F. Unlike the Sacramento area, daily peak temperatures above 90^{o}F were not a necessary condition for an ozone exceedance. This may be further evidence of the importance of transport.

Figure 5-9 shows a bar graph of the number of days above the ozone standard and the number of days above 90^{o}F for 1989 through 1997 and a bar graph of the ratio of the number of days above the ozone standard and the number of days above 90^{o}F. The plots also show the annual average exceedance concentrations and 3-yr running averages of the exceedance concentrations. These plots demonstrate that there is no discernible relationship between the number of days above the 1-hr Ozone NAAQS and the number of days above 90^{o}F. Although a majority of the exceedances of the 1-hr Ozone NAAQS occurred at temperatures above 90^{o}F, this figure demonstrates that there were many days of elevated temperatures when exceedances did not occur. In fact, the number of exceedances was shown to decrease from 1991 to 1992 although the number of days with temperatures above 90^{o}F remained constant. The number of exceedances was shown to increase from 1995 to 1996 although the number of days that experienced temperatures above 90^{o}F remained constant.

The ratio of the ozone exceedances and the days above 90^{o}F provides a simple method of adjusting the ozone air quality in a given year based on temperature influence. This ratio varies significantly by year and does not show an obvious trend.

5.2.8 Cumulative population-weighted exposure hours

Figure 5-10 presents an estimate of the cumulative population-weighted number of hours that the San Joaquin Valley Air Quality Management District (SJV AQMD) is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1998. This statistic consolidates the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances into a single indicator.

This broader perspective on air quality suggests that ozone exposure in the Bakersfield area has dramatically decreased since 1986-1988 and remained fairly level from 1989 to 1996. This dramatic finding was obscured in prior analyses of the average exceedance concentration indicator at the Arvin site. The exposure calculations have not been compiled for 1997 yet. The analysis suggests that when a broader area is considered, the air quality in the Bakersfield area has improved from the 1980s to the 1990s. However, a statistical evaluation of the exposure-hours was not available to assess the analysis errors.

5.2.9 Exceedance concentrations as a function of early morning precursor concentrations

Figure 5-11 illustrates that the exceedance concentrations appear to be related to the average early morning NO_x and VOC precursor concentrations at the Golden State Avenue site. This is true for both the average exceedance concentrations and the second highest daily maximum ozone concentration. There was little change in the average early morning NO_x and VOC measurements from 1994 to 1996 and a slight reduction in the average precursor measurements in 1997. However, note that the standard deviation (measure of variability) of both NO_x and VOC concentrations is relatively large; thus, changes are rather ambiguous. The average ratios appear to be in the VOC-limited regime, suggesting that reductions in VOC concentrations could result in lower maximum ozone concentrations.

5.3 ADJUSTMENT ANALYSES

Several of the statistical analyses that were applied to the Arvin site did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques that were applied to the ozone measurements made at the Arvin site and discussed in this section were used to assess whether the uncertainty analysis was, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques were used to estimate the uncertainty in the ozone measurements as a result of atmospheric or meteorological variability 1989 to 1997 and as a result of differences in meteorology from year to year. It is anticipated that the adjustment techniques will allow for more clear trends to be determined.

5.3.1 EPDCs as a function of early morning precursor concentrations

Figure 5-11 illustrates that the EPDCs are not related to the average early morning NO_x and VOC precursor concentrations. There was little change in the average early morning NO_x and VOC measurements from 1994 to 1996 and a slight reduction in the average precursor concentrations in 1997. The EPDCs increase from 1994 to 1996 and remain level into 1997. This finding is the opposite of the finding in Section 5.2.9. However, it is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This is observed in this case, where the EPDC in 1997 is much higher than the observed maximum concentration in 1997.

5.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis as a result of atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this work, the concept of native variability was also applied to average daily maximum ozone concentrations. This will enable a direct comparison between the analysis uncertainties and the uncertainties due to atmospheric and meteorological variability.

Figure 5-12 demonstrates the native variability about the EPDC. The following observations may be made:

- When 95 percent confidence limits are associated with the native variability estimates, significant reductions in ozone concentrations are evident between 1993 and 1994 through 1997. This observation is consistent with the findings from several of the statistical analyses (e.g., average exceedance concentration, cumulative population-weighted exposure hours) that ozone concentrations have dropped in the late 1980s and early 1990s and remained fairly level in the late 1990s at Arvin.
- The decreases observed in the ozone concentrations in 1993 are within the native variability of the EPDC and are therefore not significant. This observation is inconsistent with the earlier findings that ozone concentrations had significantly dropped in 1993 at Arvin.
- The reduction in ozone concentration from 1994 to 1997 is statistically viable and the increased ozone concentrations that were observed in 1996 are within the native variability of the measurements and are not real decreases in ozone air quality.

These findings are not consistent with trends developed in Section 4.2. However, it is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This analysis also applies native variability principles to EPDCs and is, therefore, also biased against anomalous events on both sides of the spectrum.

Figure 5-13 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS. The trends suggested in this analysis are consistent with the analysis uncertainties that were discussed earlier. When 95 percent confidence limits are considered, the ozone concentrations do not decrease dramatically (even in 1997). This suggests that the changes in the average ozone exceedance concentrations from 1989 to 1997 were not statistically significant because they were within the uncertainty due to the native variability of the average ozone concentration. This analysis also suggests that the average ozone concentrations were higher in 1993 and 1996 than they were in 1992 (see, in contrast, Figure 5-4). Finally, the improvements in air quality from 1993 to 1994 through 1997 that were suggested when the native variability of EPDC was considered is no longer clear.

5.3.3 Meteorology adjustment using the Cox and Chu probability distribution technique

Figure 5-14 shows the maximum daily ozone concentrations that have been adjusted to account for meteorology with a confidence limit of 95 percent by Cox and Chu (1998). This figure suggests that meteorology had a dramatic effect on the observed ozone concentrations in the Bakersfield MSA. This analysis was performed for a site that was in the Bakersfield MSA although the specific site location is unknown. Because the maximum ozone concentrations presented in the Cox and Chu analysis are similar to the maximum ozone concentrations experienced at Arvin, the analysis was considered anyway. However, high ozone concentrations in 1996 are not observed at the site that is the basis of this analysis; therefore, these findings should not be used to determine absolute concentrations for the adjusted ozone concentrations.

Figure 5-14 shows the actual maximum ozone concentrations, the modeled maximum ozone concentrations, and the adjusted maximum ozone concentrations. The modeled concentrations indicate how well the Weibull distribution fit the daily maximum ozone concentrations (e.g., in 1992, the model did not capture the observed daily maximum ozone concentrations well). The adjusted concentrations are adjusted from the modeled concentrations. They represent the modeled concentration that would be likely if the temperature, wind speed, and wind direction conditions within a particular year were identical to the average meteorological conditions.

When the daily maximum ozone concentrations are adjusted for meteorology, the trend in ozone concentrations appears to be very slightly downward. High ozone concentrations are lowered (e.g., 1989), and low ozone concentrations are raised (e.g., 1990, 1992, and 1997) using this smoothing technique. These findings make sense because meteorology can have both positive and negative effects on ozone formation. Finally, it is expected that the Cox and Chu method will bias against both high and low ozone concentrations that do not fit well to the probability distribution. This is demonstrated in 1992 and 1997 when the modeled ozone concentrations are dramatically different from the actual (i.e., observed) ozone concentrations. These findings are consistent with the native variability analyses that were applied to the average exceedance concentrations.

5.3.4 Meteorology adjustment using the Rao and Zurbenko filtering technique

At our request, the Kolmorov-Zurbenko filtering technique was applied to the Arvin site daily maximum ozone concentrations by a coworker of Dr. Rao, Steven Porter. **Figure 5-15** shows Mr. Porter's results for the maximum daily ozone concentrations that have been separated into two time scales of ozone variability and adjusted to filter out the effects of temperature (personal communication with Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999). Surface temperature was the sole surrogate for meteorology in this analysis. The adjusted ozone concentrations reveal a gradually decreasing trend that is due to (a) other long-term meteorological parameters (besides temperature) or (b) policy and economic changes that have caused emissions changes to the MSA.

Figure 5-15a illustrates that seasonal variability in temperature had a dramatic impact on the observed ozone concentrations (i.e., 71 percent of the ozone concentrations are explained by the normal seasonal variations in meteorology). However, nearly 30 percent of the seasonal ozone concentrations is not explained by temperature. This finding indicates that other meteorological parameters not used in this analysis are important to ozone formation in the Bakersfield MSA. Some other possible parameters include latitude, longitude, elevation, station pressure, aerosol optical depth coefficients, terrain factors, monthly vertical ozone column depth, monthly albedo factor, total cloud cover, total opaque cloud cover, and precipitable water vapor.

Figure 5-15b illustrates that the long-term reduction in ozone concentrations was not substantially influenced by temperature (only 7 percent of the variability in ozone concentrations was explained by temperature). However, a downward trend in daily maximum ozone concentrations is discernible especially when 1996 is not considered in the analysis. This suggests that some other atmospheric event was responsible for the decreasing ozone concentrations on this time scale, such as variability in a different meteorological parameter, emissions, or economic factors. Meteorological parameters, besides temperature, are likely to influence the long-term ozone formation at the Arvin site. Other meteorological parameters, besides temperature, are known to influence the seasonal ozone formation at this site. This was not observed when meteorology adjustment using the Cox and Chu probability distribution technique was used. However, it is unclear how to interpret either of the findings in the context of analysis uncertainty.

5.4 SUMMARY OF BAKERSFIELD AIR QUALITY TRENDS

Table 5-1 summarizes the findings from statistical and adjustment analyses performed on data from the Bakersfield MSA. The consensus is that ozone concentrations have declined slightly between 1987 and 1997 with little change in the 1990s. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability and meteorology was found to obscure trends.

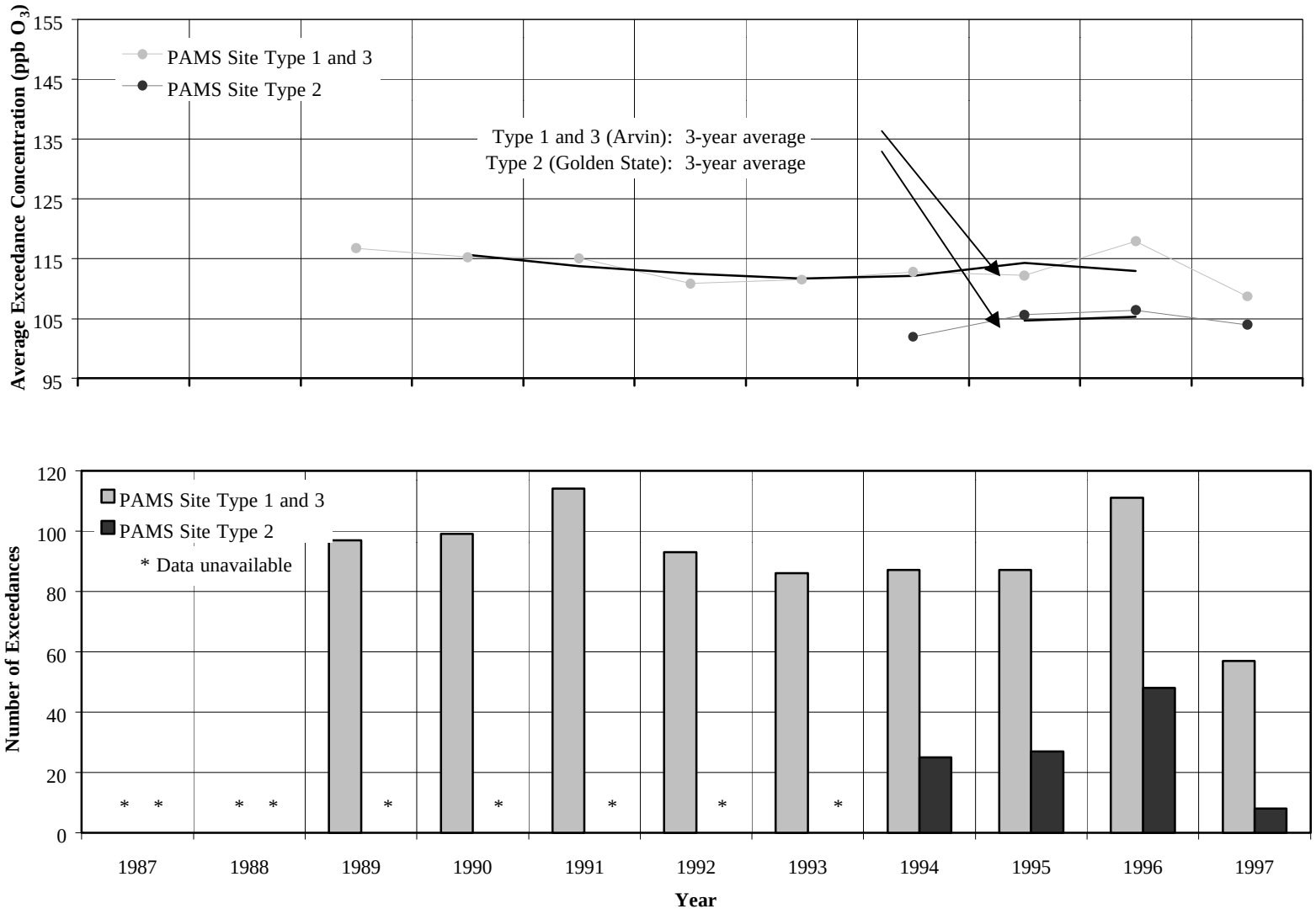


Figure 5-1. Exceedances of the California Ozone Standard at selected sites in the Bakersfield MSA.

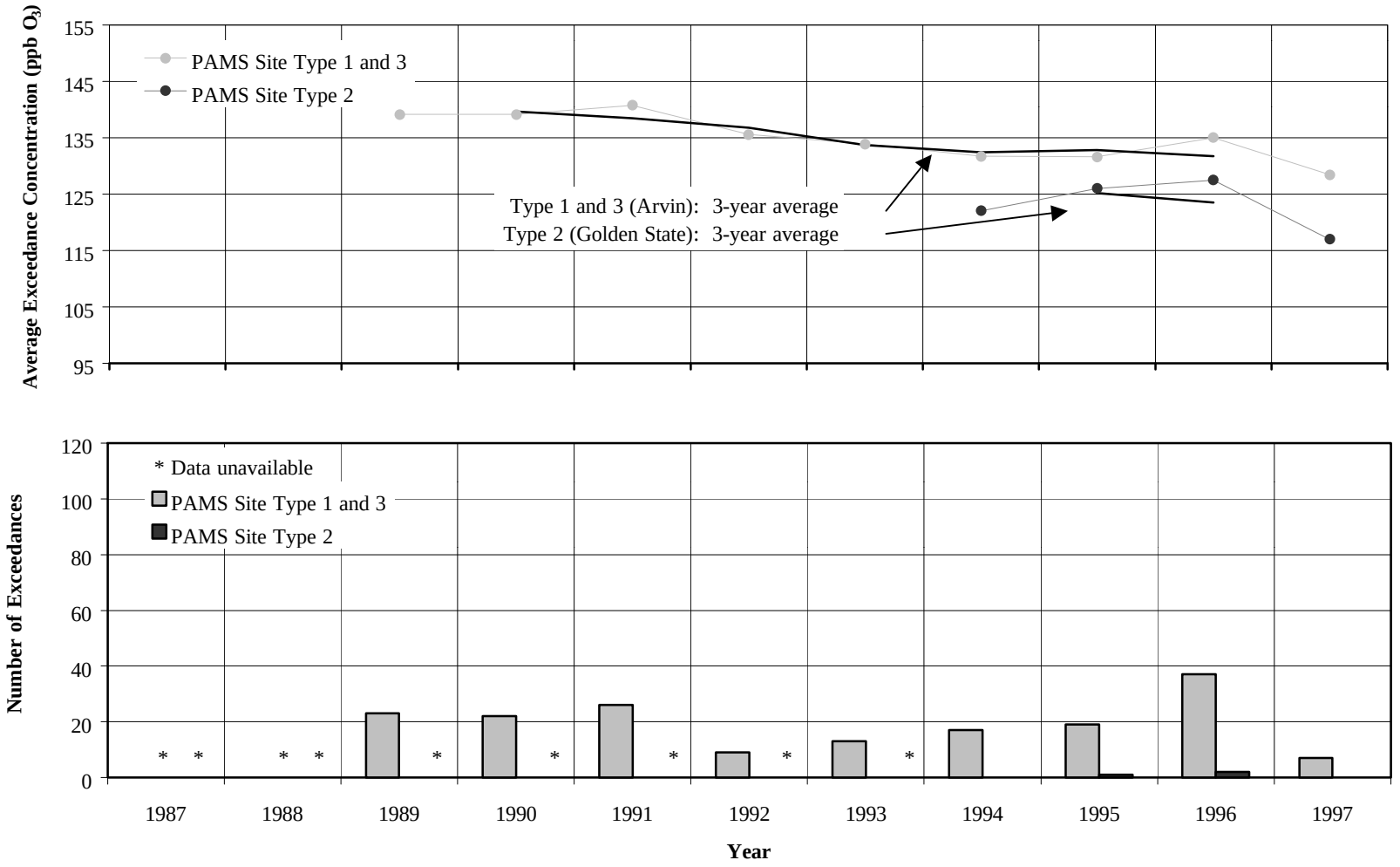


Figure 5-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the Bakersfield MSA.

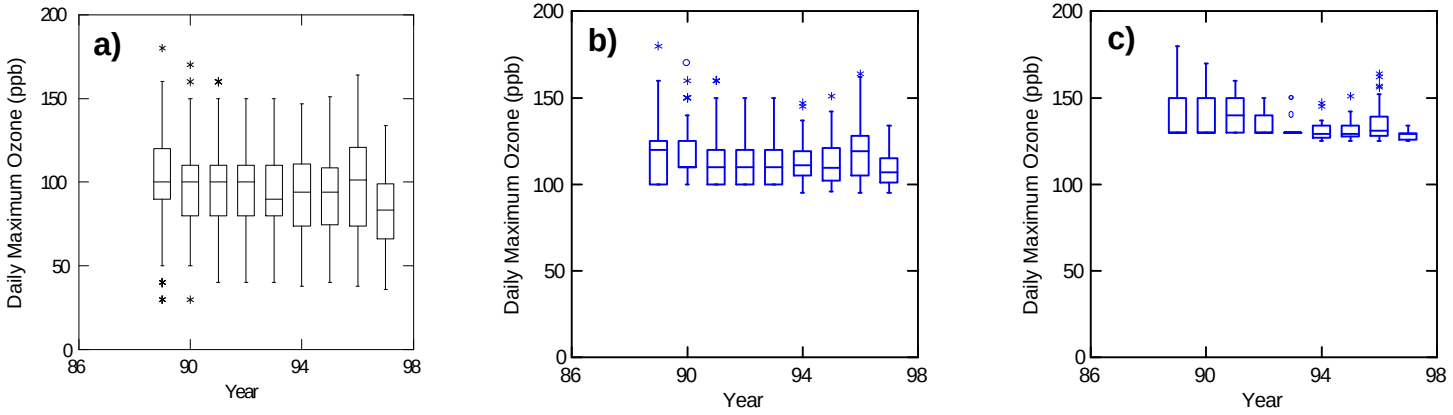


Figure 5-3. Daily maximum ozone concentrations at the Arvin site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

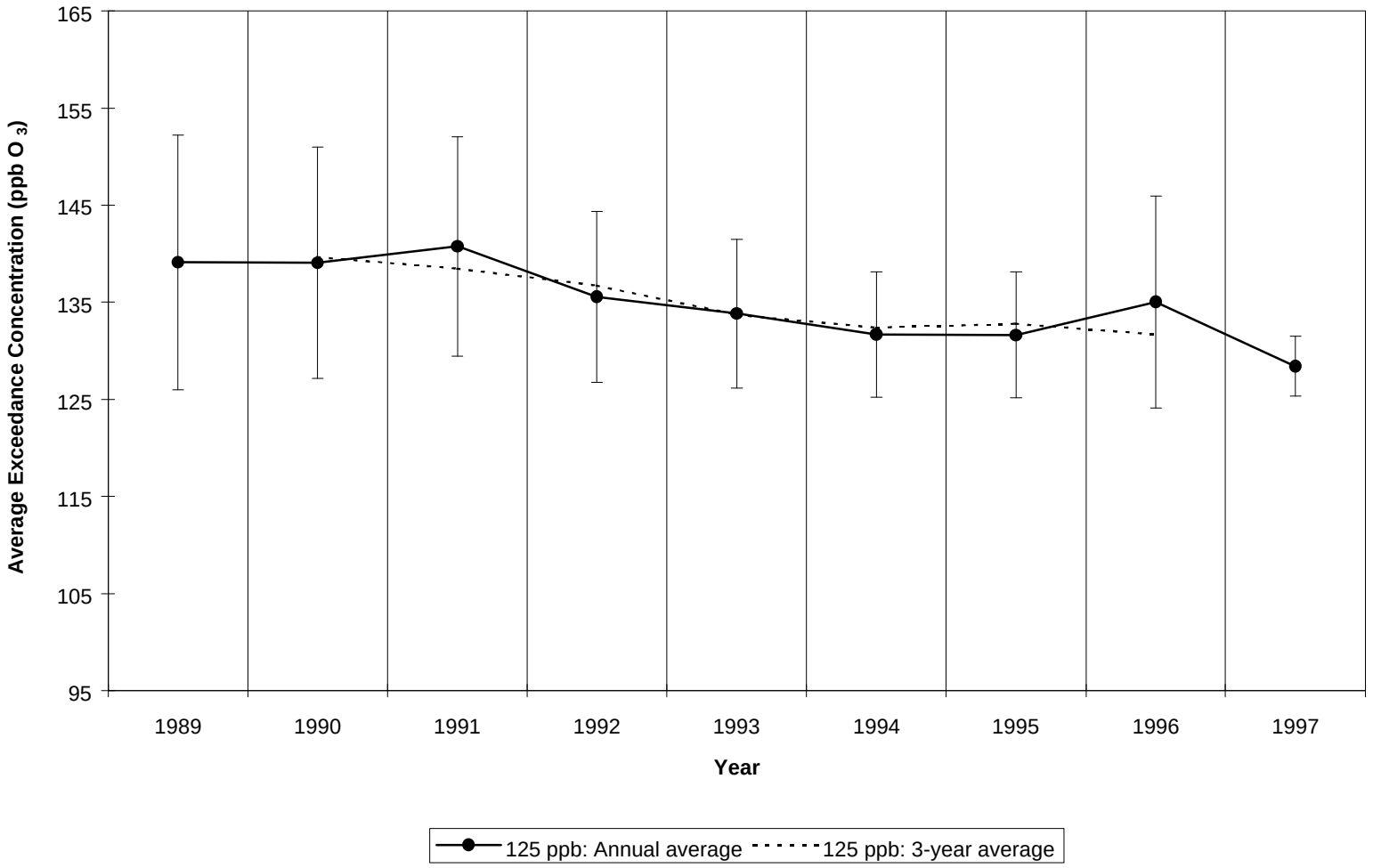


Figure 5-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty at the Arvin site. Error bars indicate the analysis uncertainty on the average ozone concentrations.

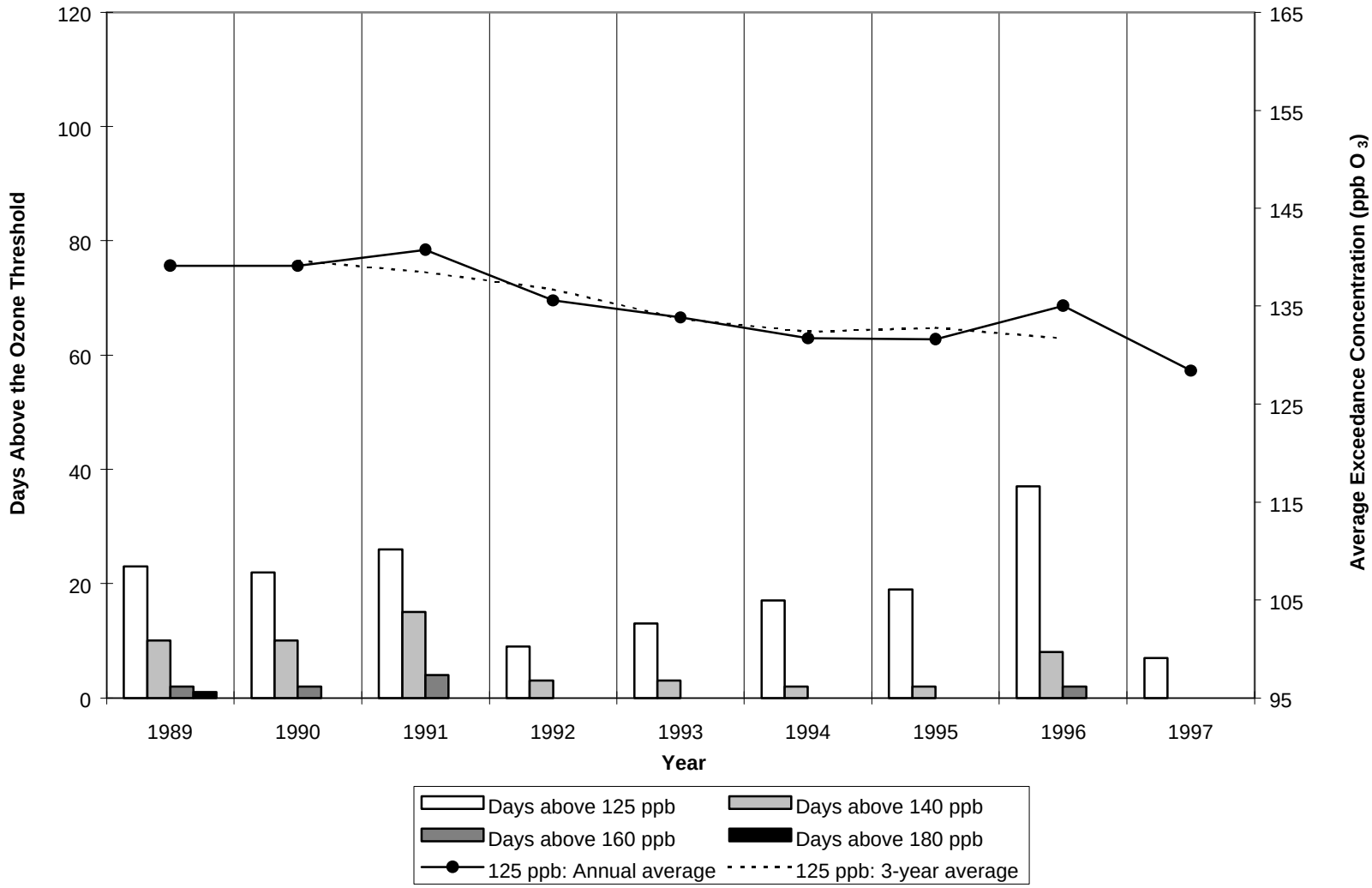


Figure 5-5. Total number of exceedances of the 1-hr Ozone NAAQS at the Arvin site.

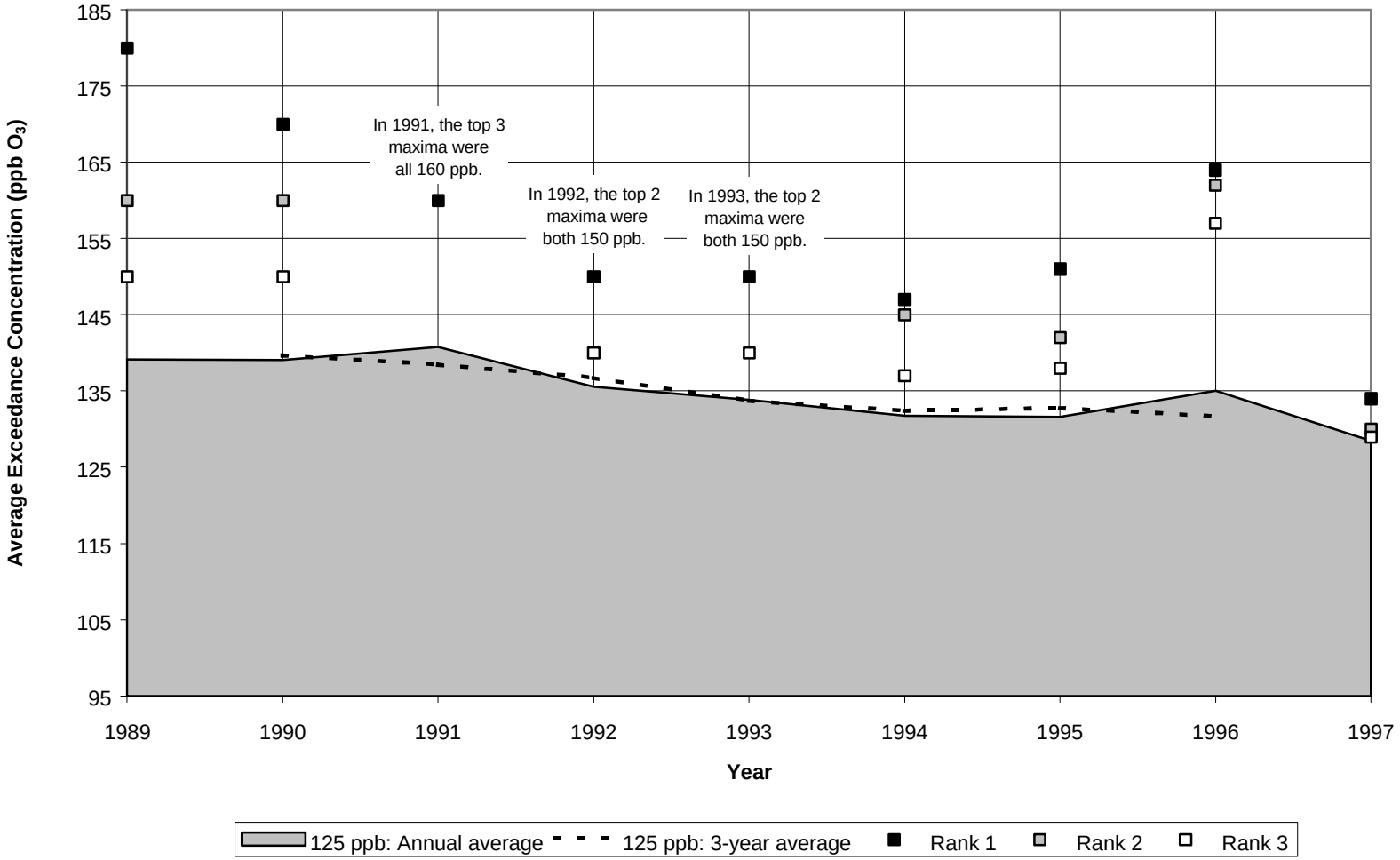


Figure 5-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS at the Arvin site.

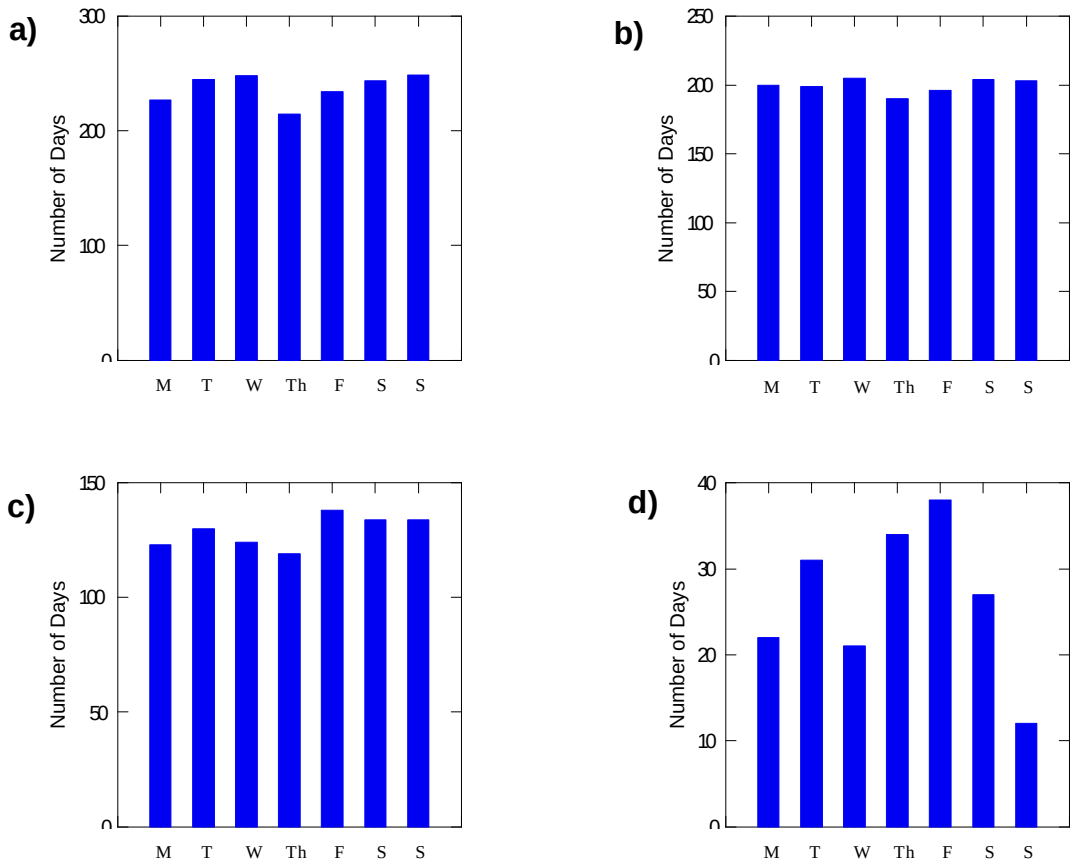


Figure 5-7. Number of days above a threshold ozone concentration by day of week at the Arvin site from 1987 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

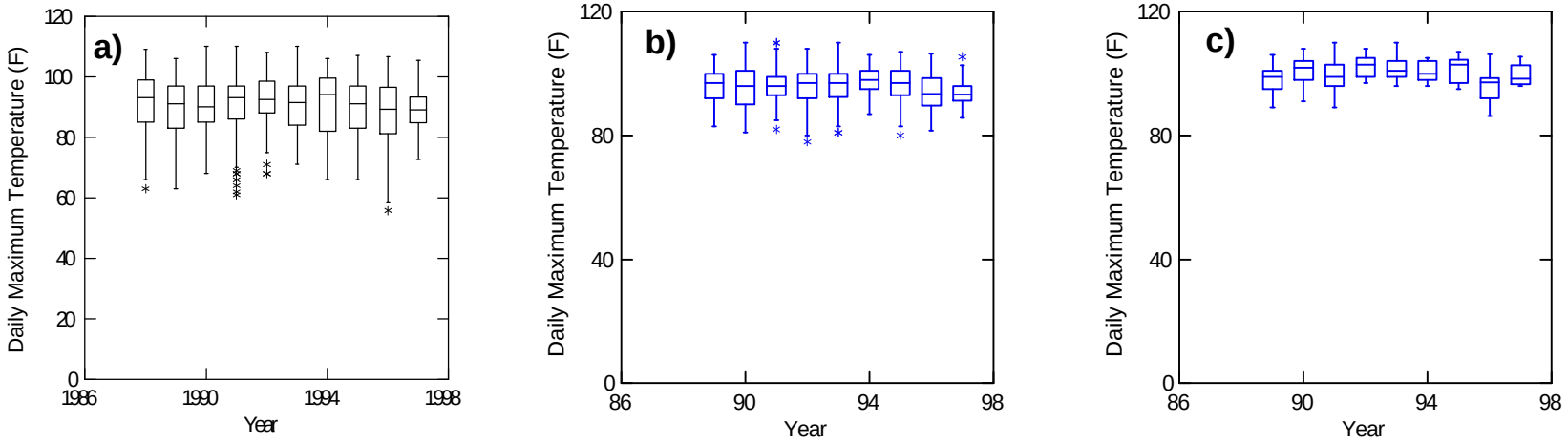
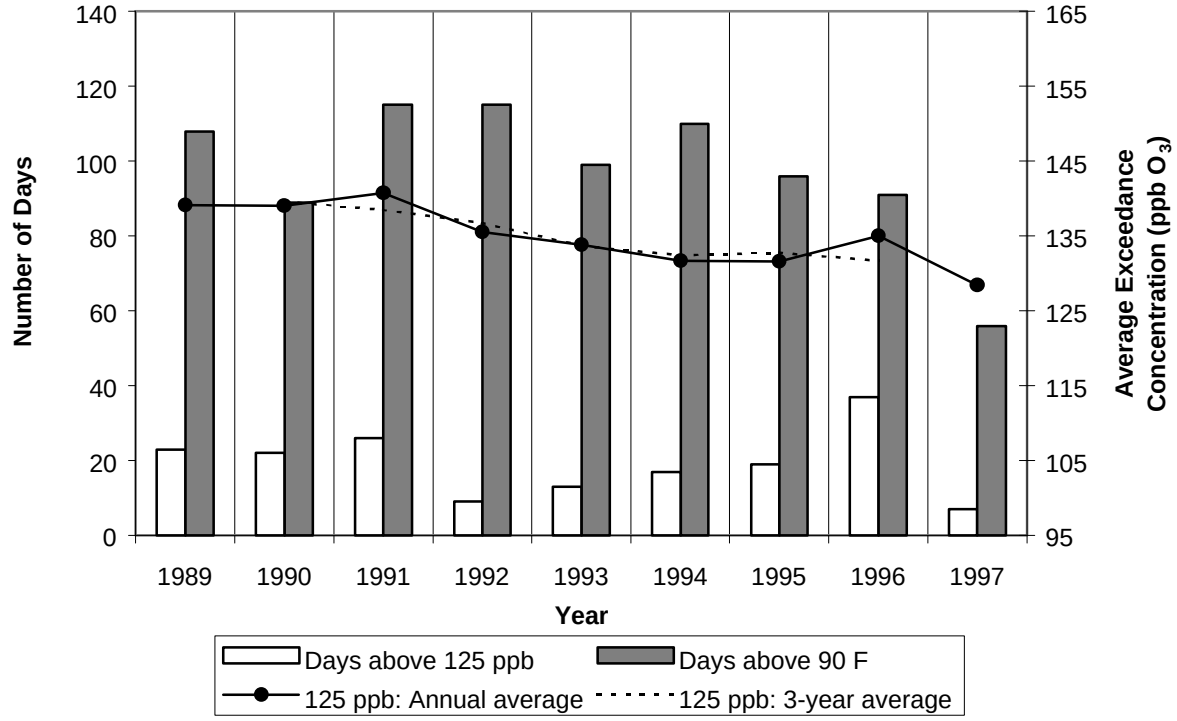


Figure 5-8. Daily maximum temperature at the Arvin site: a) all daily maximum temperatures, b) daily maximum temperature on days when the daily maximum ozone concentrations were above the California Ozone Standard, and c) daily maximum temperature on days when the daily maximum ozone concentrations were above the 1-hr Ozone NAAQS.



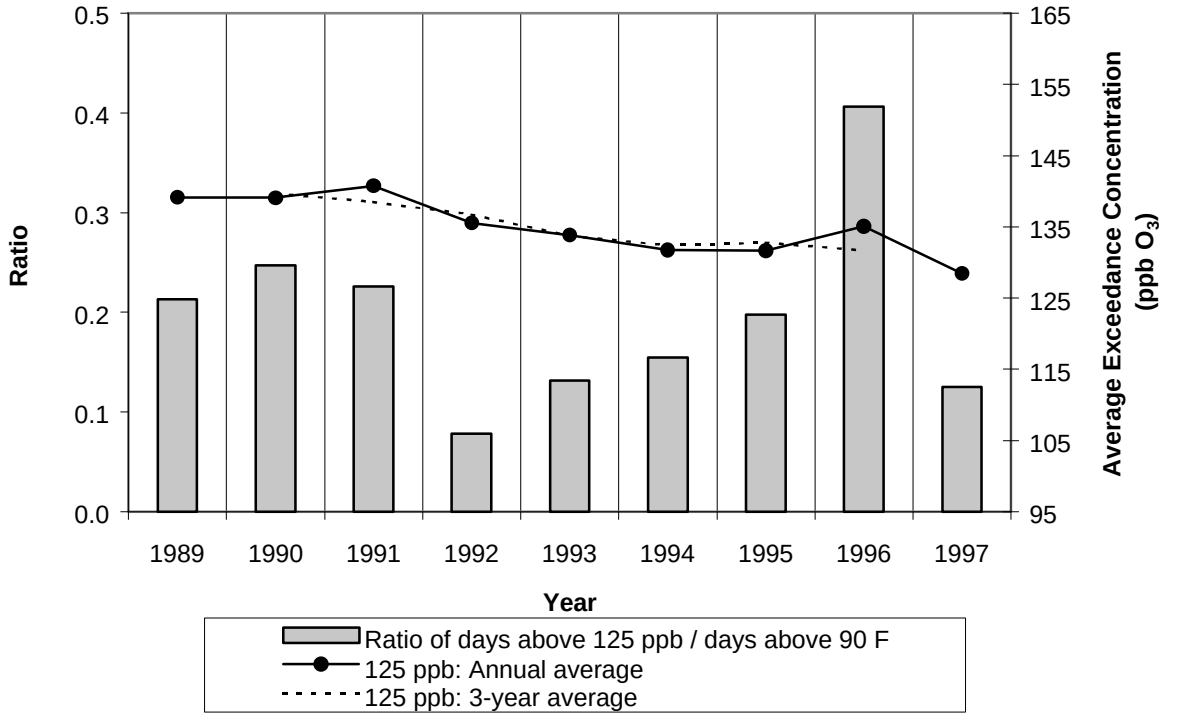


Figure 5-9. Number and ratio of the exceedances of the 1-hr Ozone NAAQS by meteorology at the Arvin site.

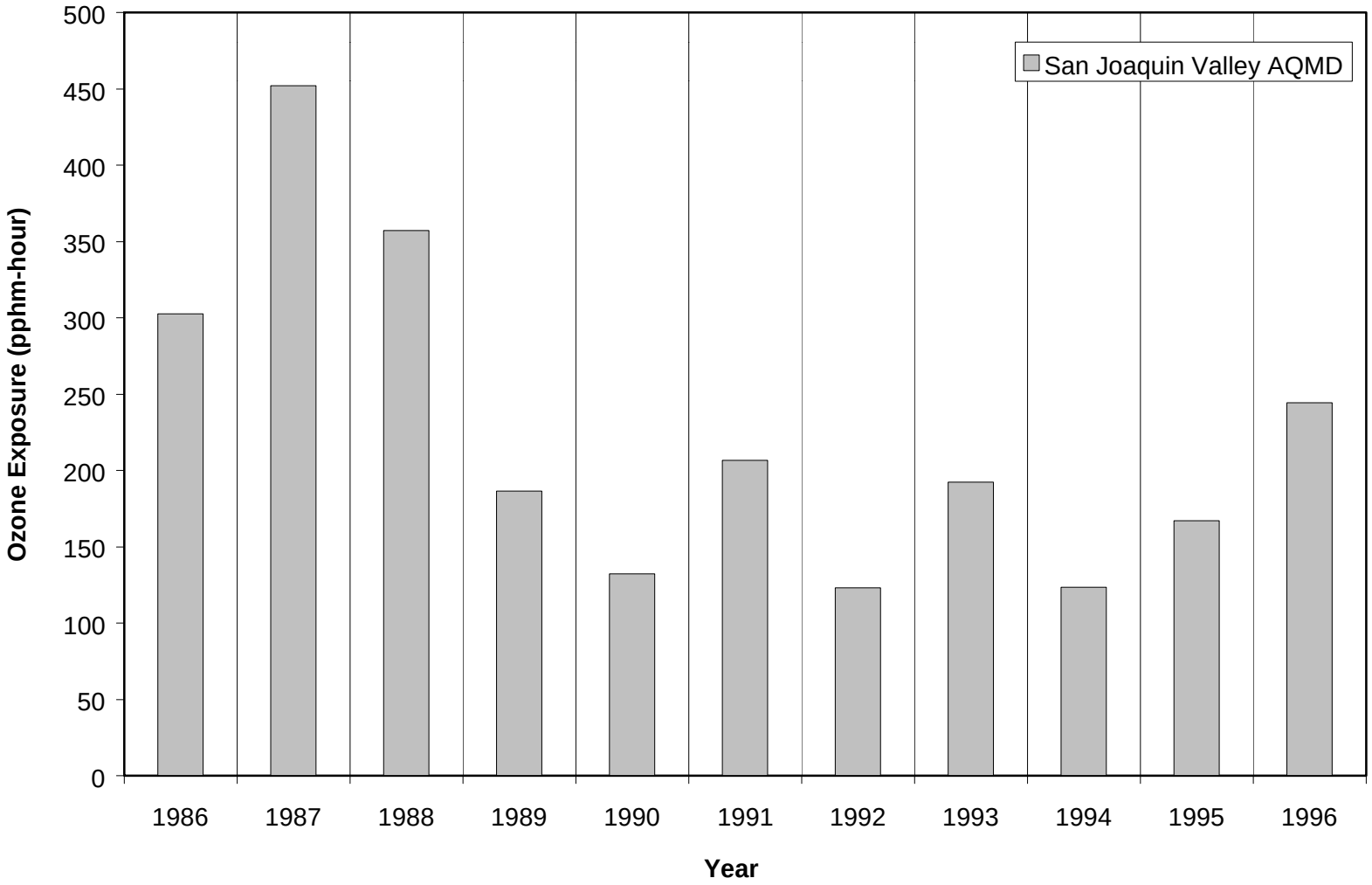


Figure 5-10. Cumulative population-weighted exposure hours of the San Joaquin Valley air basin to exceedances of the California Ozone Standard.

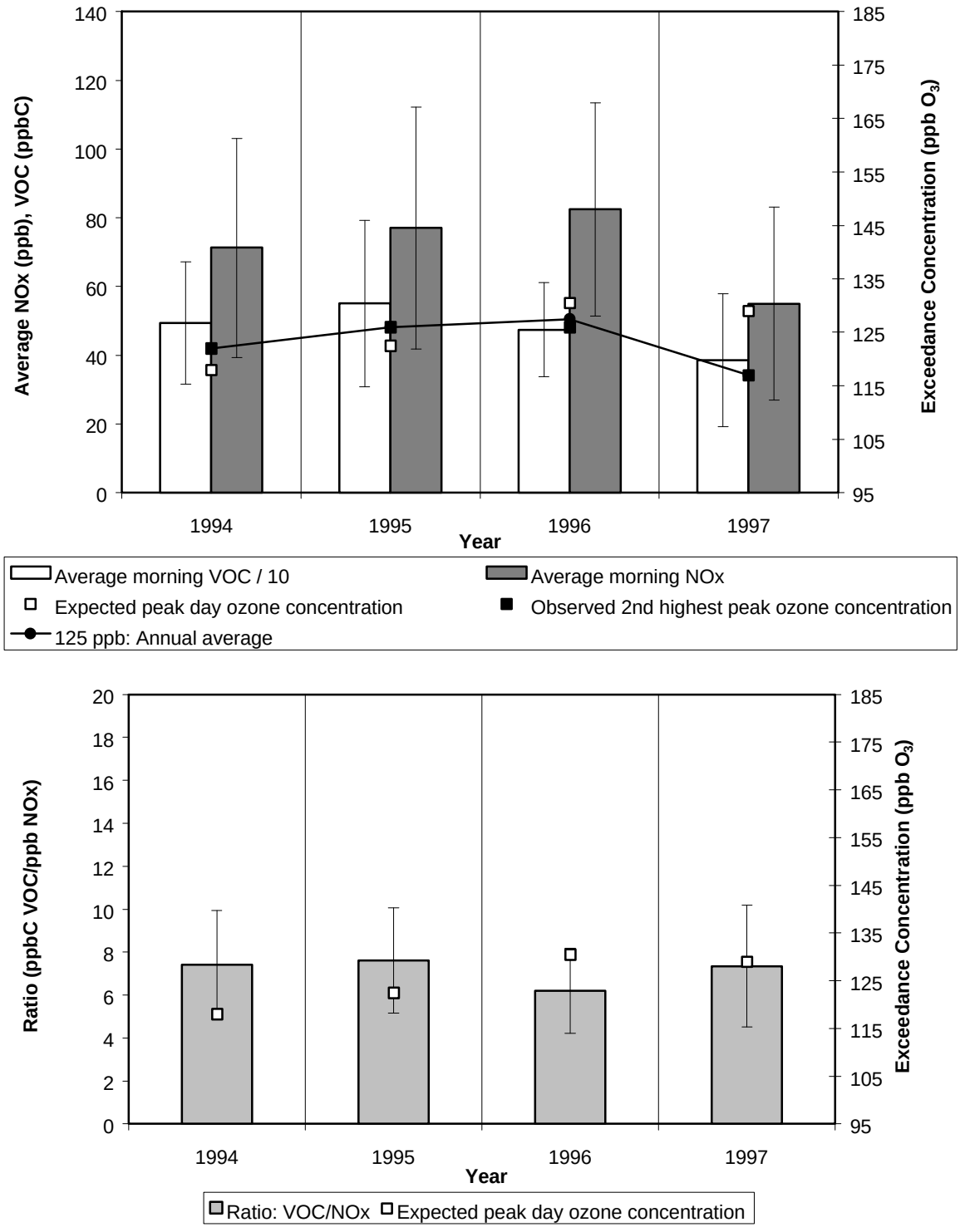


Figure 5-11. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the Golden State Avenue site.

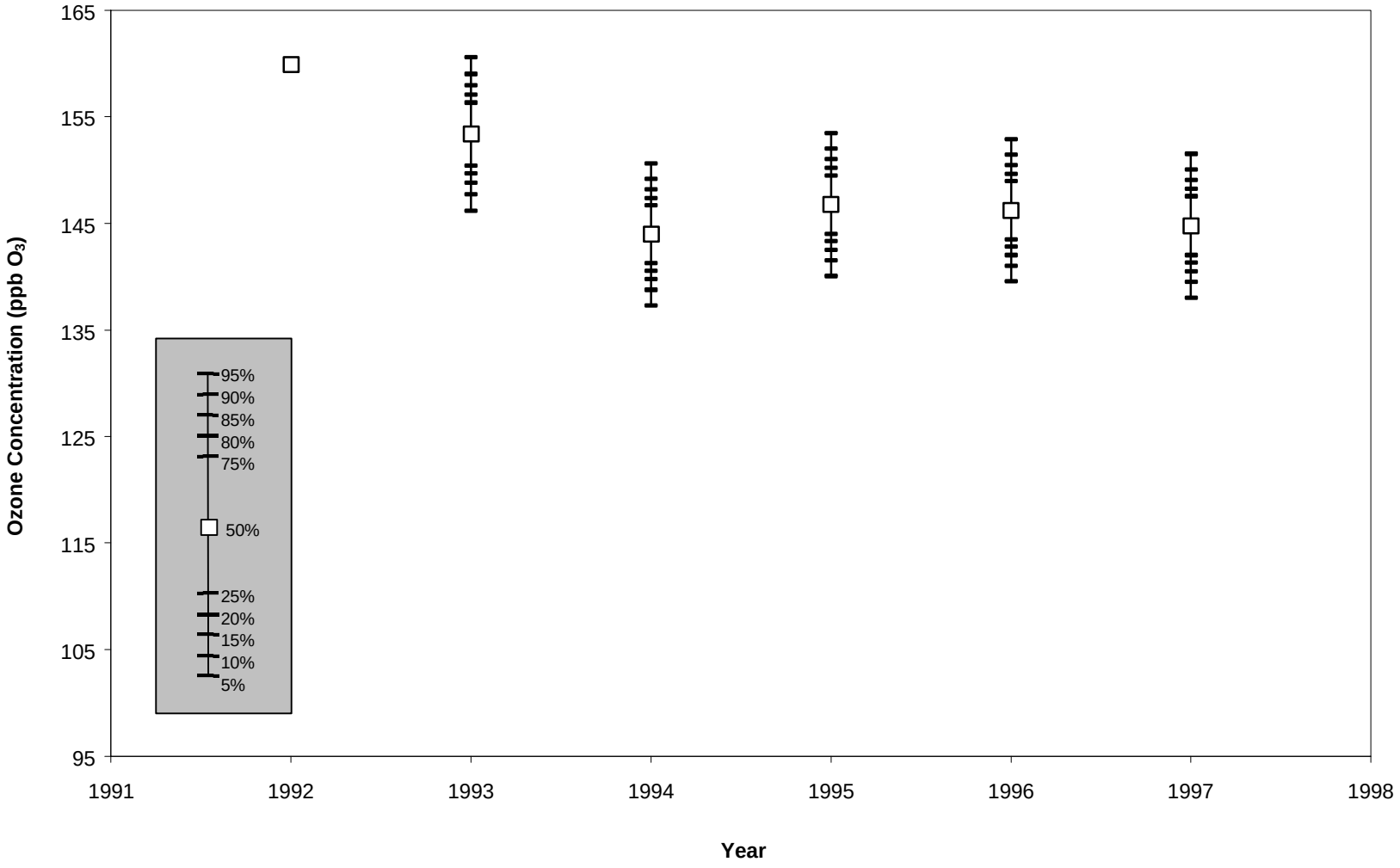


Figure 5-12. Variability of EPDC using native variability techniques for the Arvin site.

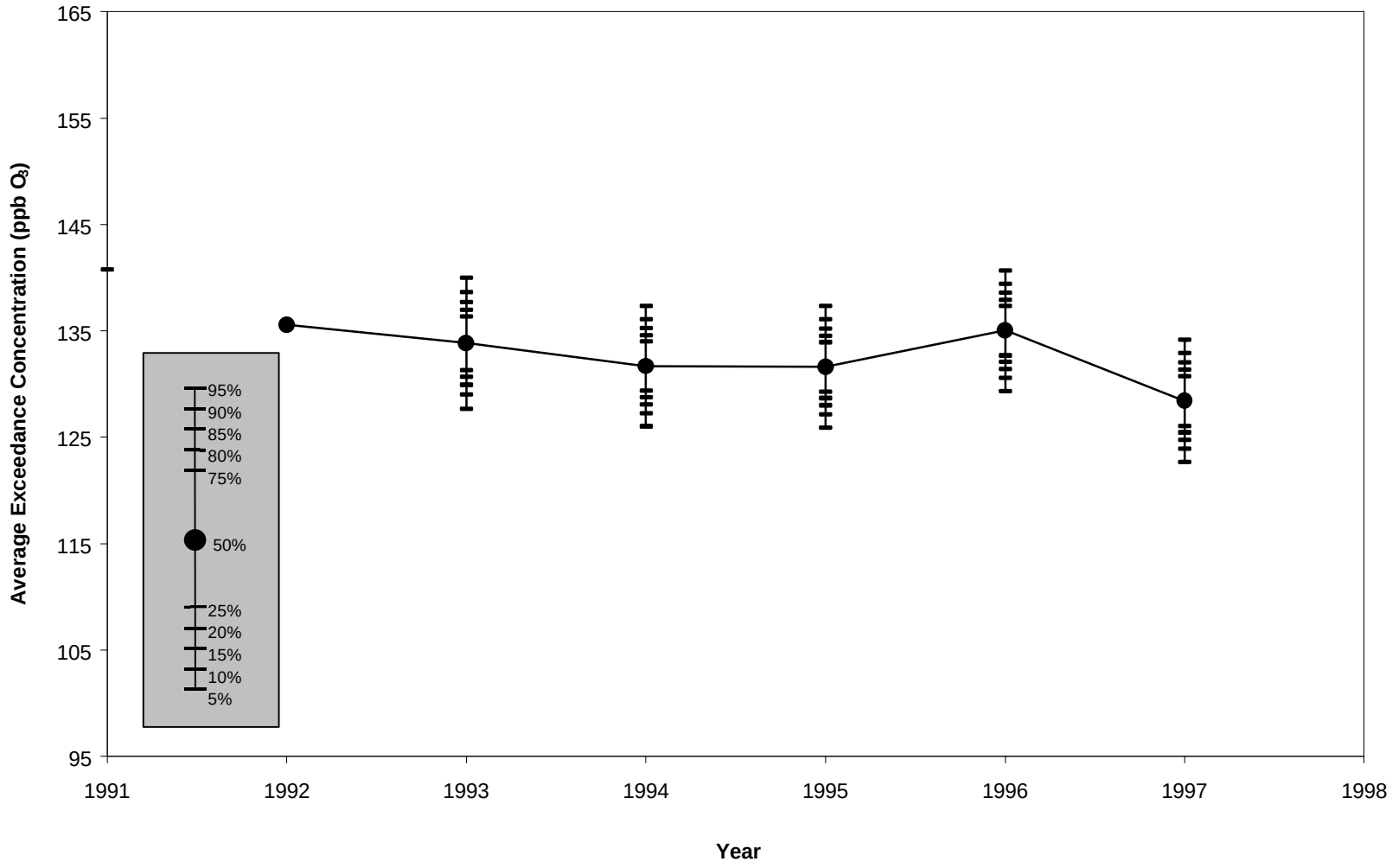


Figure 5-13. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the Arvin site.

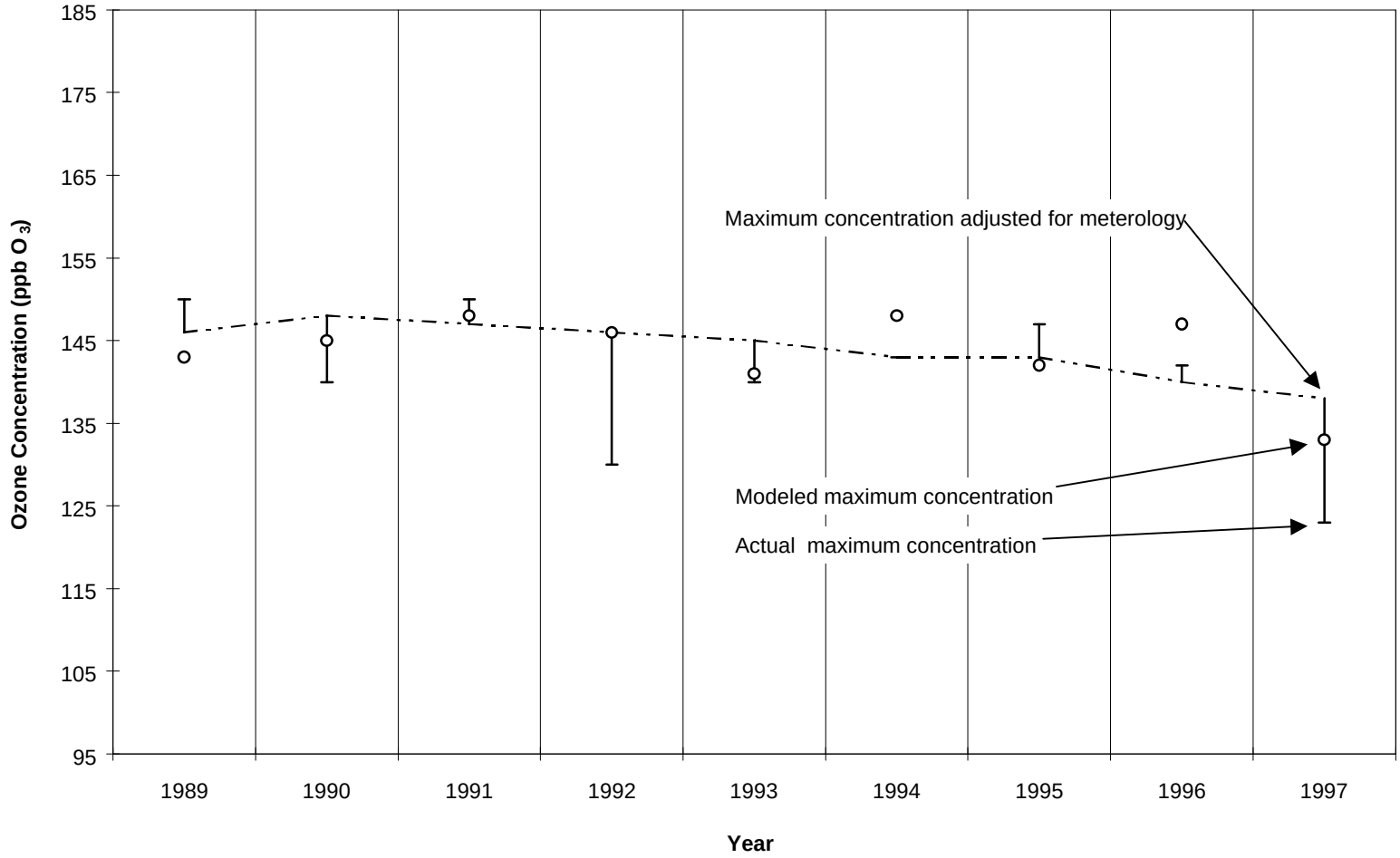
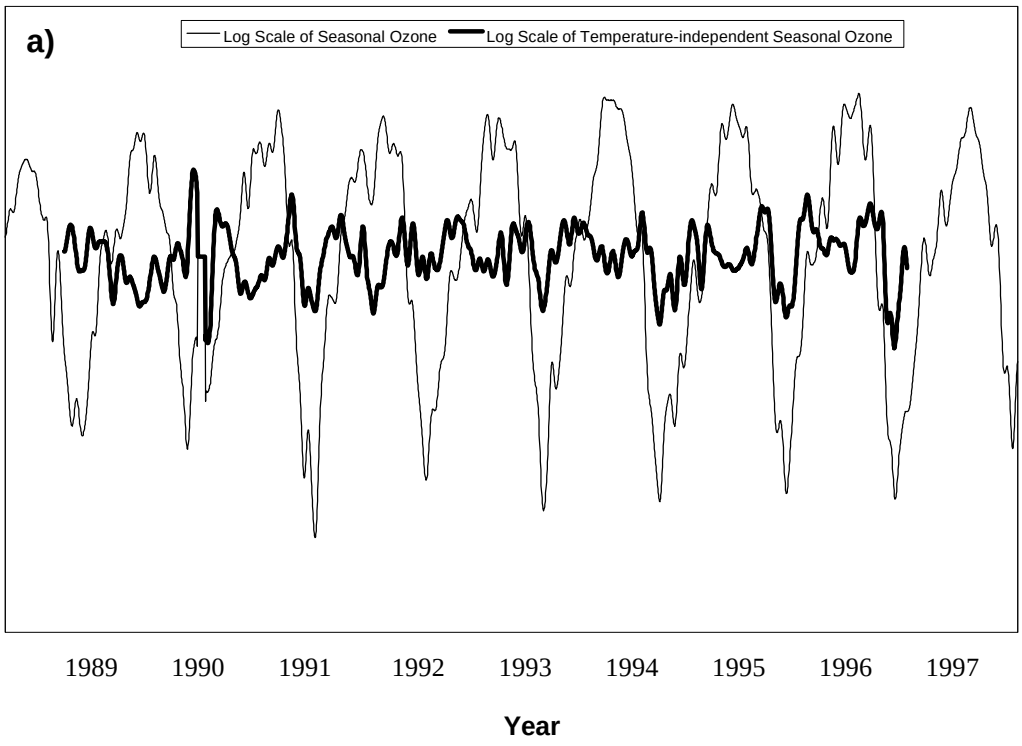


Figure 5-14. Meteorology adjustment of the maximum ozone concentrations using the Cox and Chu probability distribution technique for a site in the Bakersfield MSA.



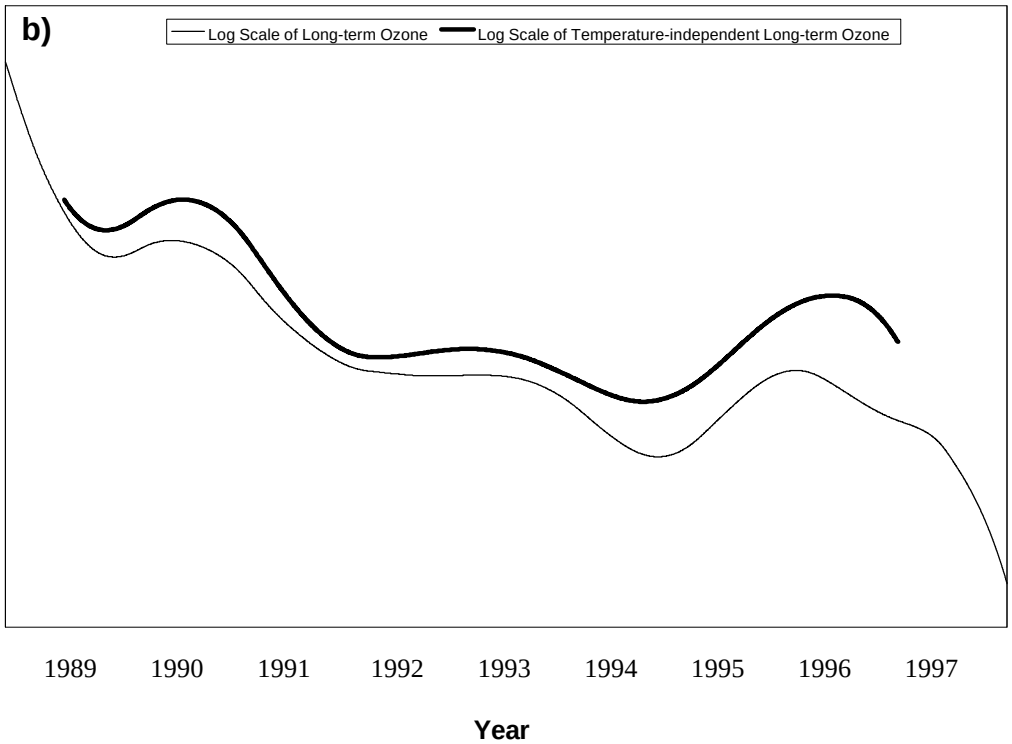


Figure 5-15. Meteorology adjustment of the Arvin site ozone concentrations using the Rao and Zurbenko filtering technique: a) seasonal component of ozone concentrations and b) long-term component of ozone concentrations (Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999).

Table 5-1. Summary of statistical and adjustment analyses of data from the Arvin site.

Statistical Analyses	Trend in 1989-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward/Inconclusive Inconclusive
Running 3-yr average of exceedance concentration	Downward/Inconclusive
Total number of exceedances	Downward/Inconclusive
Spatial distribution of exceedances	Consistent, inconclusive
Maximum concentrations	Downward
Number of exceedances by meteorology	Inconclusive
Cumulative population-weighted exposure hours	Downward/inconclusive
Morning precursor concentrations (Golden State Ave.)	Downward/Inconclusive
Morning VOC/NO_x ratios (Golden State Ave.)	No change
Adjustment Analyses	**Trend in 1989-1997 Ozone**
Expected peak day concentrations	Upward
Native variability of average daily maximum ozone concentrations	Downward
Native variability of average exceedance concentrations	Inconclusive
Meteorological adjustment using probability distribution (Cox and Chu)	Downward
Meteorological adjustment using filtering techniques (Rao and Zurbenko)	Downward

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6. FRESNO TRENDS IN OZONE

6.1 OVERVIEW

The air quality at the PAMS Type 2-like ARB Fresno 1st Street, PAMS Type 2 Clovis-Villa, and PAMS Type 3 Parlier sites in Fresno was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1-hr Ozone NAAQS were considered in the analyses. **Figure 6-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for all three sites from 1987 to 1997. **Figure 6-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for all three sites from 1987 to 1997. These figures illustrate that variability was considerable at these sites in terms of the average exceedance concentrations. When the California Ozone Standard was considered, the sites experienced different trends in the number of exceedance days. The Parlier site experienced a minimal decline in the number of exceedances per year from 1987 to 1997. The Clovis-Villa site experienced an apparent increase in the number of exceedances per year from 1991 to 1997. The Fresno 1st Street site experienced variable numbers of exceedances per year from 1990 to 1997 with no clear trends. When the 1-hr Ozone NAAQS is considered, all three sites experienced variable numbers of exceedances per year with no clear trends.

The Parlier site is classified as a PAMS Type 3 site. The analyses involving exceedances of the 1-hr Ozone NAAQS at the Parlier site are given special focus in this section because of the site's designation as a maximum ozone concentration site. The analyses involving the California Ozone Standard and the Clovis-Villa and Fresno 1st Street sites are presented in Appendix D.

The Parlier site presents several possible issues that may affect an analysis of trends:

- Reporting units changed from pphm to ppb on December 31, 1994.
- Parlier temperature measurements were unavailable from 1987 to 1994. Parlier temperature measurements were incomplete in 1997.
- Fresno Airport NWS station temperature measurements were used to supplement the Parlier measurements from 1988 to 1995.

The Clovis-Villa site is classified as a PAMS Type 2 site. This site is discussed to learn about the influence of emissions on the observed ozone concentrations. This site presents the following issues that may affect an analysis of trends:

- Clovis-Villa ozone measurements were available from 1990 through 1997. Clovis-Villa ozone measurements were incomplete in 1990 and were excluded from the analysis.
- NO_x and hydrocarbon measurements were only available from 1994 through 1997.

Several statistical analyses of the ozone air quality at these sites were performed and are discussed in this section. The analysis uncertainty is used to interpret the trends. The ARB

performed statistical analysis of the total exposure hours for the broader San Joaquin Valley air basin. This analysis is also discussed in this section.

Adjustment techniques were applied to the Parlier site to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was expected that the variability would add an additional uncertainty to the trend analyses. Adjustment techniques that were performed by other researchers for the Parlier site (or a nearby site) are also discussed to investigate the uncertainty in the trends analysis as a function of their techniques. The findings of all the adjustment techniques are discussed in terms of the statistical analyses (see Section 6.2) to establish a consensus among the different analysis approaches.

6.2 STATISTICAL ANALYSES

The statistical analyses of the Parlier air quality revealed a minimal decline in ozone concentrations at the site from 1989 to 1997 as measured by the following indicators: the number of exceedance days and the highest daily maximum ozone concentration. The analyses also showed that ozone concentrations were dramatically lower in 1997 at Parlier. Some statistics did not reveal clear trends and were also subject to large analysis uncertainties, including the average exceedance concentration over the time period and 3-yr running average exceedance concentration over the time period. The analysis of average ozone concentrations and precursor concentrations at the PAMS Type 2 Clovis-Villa site did not reveal any correlation between the observed daily maximum ozone concentrations and precursor concentrations.

6.2.1 Average exceedance concentration

Figure 6-3 shows the distribution of the daily maximum ozone concentrations at the Parlier site from 1987 to 1997. The following observations may be made:

- Figure 6-3 demonstrates that the bulk of the daily maximum ozone concentrations experienced at the site in 1990 and 1994 were lower than average, and that the bulk of the daily maximum ozone concentrations experienced at this site in 1988, 1992, and 1996 were higher than average.
- Figure 6-3a shows that the bulk of the daily ozone concentrations (i.e., interquartile range) were below the 1-hr Ozone NAAQS threshold concentration and that the median ozone concentrations exhibit a variable but slightly decreasing trend over the entire time period.
- Figure 6-3b demonstrates that decreasing ozone concentrations in 1997 are not as clear when the exceedances of the California Ozone Standard are considered.
- In Figure 6-3c, the presence of smaller ranges in the bulk of the ozone concentrations since 1987 suggests that high exceedance concentrations were less common in the 1990s. The lack of outlier points in the late 1990s suggests that high exceedances were

uncommon and the majority of exceedances were within the interquartile range of the median exceedance concentration.

Figure 6-4 shows the average exceedance concentrations at the Parlier site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in the previous figure are not distinguishable when the analysis uncertainty of the exceedance concentrations is considered. However, a slight reduction in the average concentration of the exceedances of the 1-hr Ozone NAAQS is observable between 1987 and 1997.

6.2.2 Running 3-year average of exceedance concentrations

The running 3-year average concentrations of the 1-hour Ozone NAAQS exceedances are shown in Figure 6-4. The figure illustrates that the average exceedance concentrations are unchanged over the entire time period when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period. The stability of the 3-year average exceedance concentration is consistent with the inability to determine trends in the average exceedance concentration when the analysis uncertainty was considered; this could also suggest that anomalous events (such as atypical meteorological events) are responsible for the variations in the average exceedance concentrations in several years (e.g., 1990, 1992, 1994, 1996, and 1997.

6.2.3 Total number of exceedances of the standard

Although the average exceedance concentration did not dramatically change from the late 1980s to the late 1990s, the number of exceedance days has definitely decreased. **Figure 6-5** demonstrates this point. The figure also demonstrates that the number of exceedance days associated with daily maximum ozone concentrations that were above 140 ppb decreased from 1987 to 1997. Exceedance concentrations above 160 ppb were uncommon after 1987. Exceedance concentrations above 180 ppb were not observed after 1987.

Figure 6-5 also demonstrates that an increase in the number of exceedances of the 1-hr Ozone NAAQS increased in 1996 as did higher average exceedance concentrations. In 1992 and 1993, the total number of exceedances did not change dramatically, but the concentration of the exceedances increased. An uncommonly small number of exceedances of the 1-hr Ozone NAAQS and lower average exceedance concentrations occurred in 1990 and 1994.

6.2.4 Identification of the highest exceedance concentrations

Figure 6-6 shows the top three exceedance concentrations that occurred at the Parlier site and illustrates that the highest daily maximum ozone concentration each year decreased from 1987 to 1997. This figure also demonstrates that the highest exceedance concentrations

were closer to the average exceedance concentration during the years with fewer exceedances (e.g., 1990, 1994, and 1997). The highest exceedance concentrations were much greater than the average exceedance concentrations during years with more exceedances and higher average exceedance concentrations (e.g., 1987, 1992, and 1996). This finding suggests that the years with fewer exceedances and lower exceedance concentrations are more representative of typical (i.e., average) air quality at the Parlier site.

6.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated (**Figure 6-7**), it appears that fewer exceedances of the 1-hr Ozone NAAQS occurred on Sunday (Figure 6-7c). However, daily maximum ozone concentrations do not significantly vary by day of week when lower thresholds are considered. This suggests that, statistically, there may be less chance of exceedances of the 1-hr Ozone NAAQS on Sundays. Other studies have demonstrated this pattern, and it has been speculated that it is due to differences in emissions. However, at lower thresholds, the daily differences were not significant. These findings are consistent with the same analysis applied to the Bakersfield area data.

6.2.6 Spatial distribution of exceedances

Figure 6-2 illustrates that there was considerable variability at the PAMS Type 2-like ARB Fresno 1st Street, PAMS Type 2 Clovis-Villa, and PAMS Type 3 Parlier sites in terms of the average exceedance concentrations. When the 1-hr Ozone NAAQS is considered, all three sites experienced similar variability in the numbers of exceedances per year with no clear trends. When the California Ozone Standard was considered (Figure 6-1), the sites experienced different trends in the number of exceedance days. The Parlier site experienced a minimal decline in the number of exceedances per year from 1987 to 1997. The Clovis-Villa site experienced an apparent increase in the number of exceedances per year from 1991 to 1997. The Fresno 1st Street site experienced variable numbers of exceedances per year from 1990 to 1997.

A comparison of the air quality at the three sites also revealed two interesting features:

- The expected relationship between the PAMS Type 2 and PAMS Type 3 sites was not observed. For example, the PAMS Type 2 site consistently experienced higher average exceedance concentrations than did the PAMS Type 3 site. During several years, the PAMS Type 3 site experienced fewer exceedances and higher daily maximum ozone concentrations than did the PAMS Type 2 site (e.g., 1992, 1994, 1995, and 1997).
- The PAMS Type 2-like ARB Fresno 1st Street site site was the only site of the three to experience the dramatic reductions in number of exceedance days of the California Ozone Standard that many sites throughout California also experienced in 1997. However, ozone concentrations were only available for the Clovis-Villa site from 1991 to 1997 and for the Fresno 1st Street site from 1990 to 1997. Therefore it is

difficult to distinguish whether the reductions in number of exceedances from the late 1980s to the late 1990s at the Parlier site are consistent with the changes in the air quality at the other sites.

The variability in the ozone concentrations at the three sites makes it difficult to assess the impact of regional transport on air quality in the Fresno MSA.

6.2.7 Number of exceedances of the standard by meteorology

Temperature measurements were made at the Parlier site from 1995 to 1997. In 1997, these measurements were incomplete. Because the temperature measurements were discontinuous and did not span the time period for which ozone measurements were available, Parlier site temperature measurements were supplemented with measurements made at the NWS station at the Fresno Airport from 1988 to 1995. The temperature measurements at the Parlier site and at the Fresno Airport NWS station demonstrated excellent correlation for the years of concurrent temperature measurements. The correlation plot is presented in Appendix A. The subsequent analyses involving temperature measurements use the supplemented data set.

Figure 6-8 shows the distribution of the daily maximum temperatures from 1988 to 1997. The figure shows that the bulk of the daily maximum temperatures (i.e., interquartile range) were above 90°F. Further, the daily maximum temperatures were not significantly different on exceedance days than they were on average during the summertime except for higher than average daily maximum temperature measurements in 1990 and 1994. These were years when dramatically lower numbers of exceedances of the standards were experienced. This suggests that the meteorology (with temperature as an indicator of meteorology in general) was atypical of the average summertime meteorology at the Parlier site during the years that experienced the fewest exceedances of the California Ozone Standard and the 1-hr Ozone NAAQS. Figure 6-8c also identifies that the bulk daily maximum temperatures on NAAQS exceedance days were lower in the late 1990s than they were in the late 1980s. This suggests that the higher number of exceedances from 1995 to 1997 occurred in less ozone-formation conducive conditions. This is an unexpected finding.

Figure 6-9 shows a bar graph of the number of days above the ozone standard and the number of days above 90°F for 1987 - 1997 and a bar graph of the ratio of the number of days above the ozone standard and the number of days above 90°F. The plots also show the annual average exceedance concentrations and 3-yr running averages of the exceedances concentrations. These plots demonstrate that there is no discernible relationship between the number of days above the 1-hr Ozone NAAQS and the number of days above 90°F. A majority of the exceedances of the 1-hr Ozone NAAQS occurred at temperatures above 90°F (except in 1996 when only 80 percent of the exceedances of the 1-hr Ozone NAAQS were associated with elevated temperatures). However, Figure 6-9 demonstrates that elevated temperatures occurred on many days when exceedances did not occur. In fact, from 1988 to 1989, the number of exceedances decreased although the number of days with temperatures

above 90°F remained constant. From 1991 to 1992, the number of exceedances remained constant although the number of days with temperatures above 90°F increased. From 1994 to 1996,the number of exceedances increased although the number of days with temperatures above 90°F decreased. These observations suggest that the decreased number of exceedance days in 1990 is potentially the result of changing meteorology, while the dramatic changes in number of exceedance days in 1992, 1994, and 1996 are potentially the result of changes in emissions.

The ratio of the ozone exceedances and the days above 90°F provides a simple method of adjusting the ozone air quality in a given year based on temperature influence. This ratio varies significantly by year with the ratios in the late 1990s similar to the ratios in the late 1980s.

6.2.8 Cumulative population-weighted exposure hours

Figure 6-10 shows an estimate of the cumulative population-weighted number of hours that the San Joaquin Valley Air Quality Management District (SJV AQMD) is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1998. This statistic consolidates the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances into a single indicator.

This broader perspective on air quality suggests that ozone exposure in the Fresno area has dramatically decreased since 1987 and 1988, and remained fairly level from 1989 to 1996. Figure 6-10 confirms that ozone exposure increased in 1991, 1993, and 1996. The exposure calculations have not been compiled for 1997 yet. The analysis suggests that when a broader area is considered, the air quality in the San Joaquin Valley air basin improved from the late 1980s to the 1990s but has not shown continued improvement. However, a statistical evaluation of the exposure-hours was not available to assess the analysis errors.

6.2.9 Exceedance concentrations as a function of early morning precursor concentrations

Figure 6-11 illustrates that the exceedance concentrations are not clearly related to the average early morning NO_x and VOC precursor concentrations. The 1994 to 1997 average exceedance concentrations and morning precursor concentrations are relatively unchanged. Trends in the second highest daily maximum ozone concentration during the time period are difficult to assess. The average VOC/NO_x ratios appear to be in the VOC-limited regime, suggesting that reductions in VOC concentrations could result in lower maximum ozone concentrations. The ratios do not show a significant change among the years.

6.3 ADJUSTMENT ANALYSES

Several statistical analyses applied to the Parlier site did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques applied to the ozone measurements made at the Parlier site and discussed in this section are used to assess whether the uncertainty analysis is, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques were used to estimate the uncertainty in the ozone measurements as a result of atmospheric or meteorological variability from 1987 to 1997 and differences in meteorology from year to year. It is anticipated that the adjustment techniques will allow for more clear trends to be determined.

6.3.1 EPDCs as a function of early morning precursor concentrations

Figure 6-11 illustrates that the EPDCs and the average early morning NO_x and VOC precursor concentrations showed little change from 1994 to 1997. The EPDCs decreased slightly from 1993/1994 to 1995 and remained level from 1995 to 1997. These data are not sufficient to determine a precise cause and effect relationship between precursor concentrations and the EPDCs. This finding is consistent with the conclusions in Section 6.2.9. However, it is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This is observed in this case where the EPDC in 1993 and 1994 is much higher than the observed second highest maximum concentrations. This finding raises questions regarding the evaluation of ozone trends at the Parlier site using the EPDC statistic (see Section 2).

6.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis as a result of atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this work, the concept of native variability was also applied to average daily maximum ozone concentrations. Thus, the uncertainties as a result of the analysis and the uncertainties as a result of atmospheric and meteorological variability can be directly compared.

Figure 6-12 demonstrates the native variability about the EPDC for the Parlier site. When 95 percent confidence limits are associated with the native variability estimates, significant reductions in ozone concentrations are seen from 1991 to 1997 with a single exception, 1993. This is consistent with the findings in several of the statistical analyses (e.g., number of exceedance days, average exceedance concentration) that ozone concentrations have dropped since the late 1980s and have remained fairly level in the 1990s at the Parlier site. It is interesting that native variability indicates that the daily maximum ozone concentrations were higher in 1993 than in any other year from 1989 to 1997. Native variability also identified that the daily maximum ozone concentrations were higher in 1996; this has been confirmed using other indicators and suggests that the higher number of exceedances experienced during this

year are real and statistically significant. It is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This analysis also applies native variability principles to EPDCs and is therefore biased against anomalous events on both sides of the spectrum.

Figure 6-13 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS. When 95 percent confidence limits are considered, the ozone concentrations do not decline significantly (even in 1997). This suggests that changes in the ozone concentrations from 1987 to 1997 were not significant because they were within the uncertainty due to the native variability of the average ozone concentrations. Finally, the decrease in ozone concentrations from 1994 to 1997 that was suggested when the native variability of EPDC was considered is no longer clear.

6.3.3 Meteorology adjustment using the Cox and Chu probability distribution technique

Figure 6-14 shows the maximum daily ozone concentrations that have been adjusted to account for meteorology with a confidence limit of 95 percent by Cox and Chu (1998). This figure suggests that meteorology has had a dramatic effect on the observed ozone concentrations in the Fresno MSA. This analysis was performed for a site that was in the Fresno MSA although the specific site location is unknown. Because the maximum ozone concentrations presented in the Cox and Chu analysis are similar to the maximum ozone concentrations experienced at the Parlier site, the analysis was considered anyway. These findings should not be used to determine absolute concentrations for the adjusted ozone concentrations.

Figure 6-14 shows the actual maximum ozone concentrations, the modeled maximum ozone concentrations, and the adjusted maximum ozone concentrations. The modeled concentrations indicate how well the Weibull distribution fit the daily maximum ozone concentrations. For example, in 1988 and 1990, the model did not capture the observed daily maximum ozone concentrations well. The adjusted concentrations are adjusted from the modeled concentrations. They represent the modeled concentration that would be likely if the temperature, wind speed, and wind direction conditions within a particular year were identical to the average meteorological conditions.

When the daily maximum ozone concentrations are adjusted for meteorology, the trend in ozone concentrations appears to be gradually decreasing. High ozone concentrations are lowered (e.g., 1996), and low ozone concentrations are raised (e.g., 1990) using this smoothing technique. These findings make sense because meteorology can have both positive and negative effects on ozone formation. Finally, it is expected that the Cox and Chu method will bias against both high and low ozone concentrations that do not fit well to the probability distribution. This is demonstrated in 1988 and 1990 when the modeled ozone concentrations are dramatically different than the actual (i.e., observed) ozone concentrations. These findings suggest a gradually decreasing trend that was not clear when native variability was applied to the average exceedance concentrations at the Parlier site. This analysis also suggests that the dramatic decrease in number of exceedance days in 1990 and the increase in number of

exceedance days in 1996 are the result of meteorology. This is consistent with the statistical meteorology analysis that was performed in Section 6.2.7.

6.3.4 Meteorology adjustment using the Rao and Zurbenko filtering technique

At our request, the Kolmorov-Zurbenko filtering technique was applied to the Parlier daily maximum ozone concentrations by a coworker of Dr. Rao, Steven Porter. **Figure 6-15** shows Mr. Porter's results for the maximum daily ozone concentrations that have been separated into two time scales of ozone variability and adjusted to filter out the effects of temperature (personal communication with Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999). Surface temperature was the sole surrogate for meteorology in this analysis. The adjusted ozone concentrations reveal a wildly variable trend that is due to other long-term meteorological parameters besides temperature, or policy and economic changes that have caused emissions changes in the Fresno MSA. This trend is consistent with the inconclusive findings of several other analyses.

Figure 6-15a illustrates that seasonal variability in temperature had a dramatic impact on the observed ozone concentrations (i.e., 65 percent of the ozone concentrations are explained by the normal seasonal variations in meteorology). However, nearly 35 percent of the seasonal ozone concentrations is not explained by temperature. This indicates that other meteorological parameters not used in this analysis are important to ozone formation in the Fresno MSA. Other possible parameters include latitude, longitude, elevation, station pressure, aerosol optical depth coefficients, terrain factors, monthly vertical ozone column depth, monthly albedo factor, total cloud cover, total opaque cloud cover, and precipitable water vapor.

Figure 6-15b illustrates that the long-term reduction in ozone concentrations was not substantially influenced by temperature; in fact, only 4 percent of the variability in ozone concentrations was explained by temperature. However, the difference between the long-term ozone and the temperature-adjusted (i.e., temperature-independent) long-term ozone varies more in 1994, 1996, and 1997. This suggests that temperature has a greater than 4 percent effect on the observed ozone concentrations in these years. For the most part, these figures suggest that some other atmospheric event was responsible for the changing ozone concentrations on this time scale, such as variability in different meteorological parameters, emissions, or economic factors. This variable trend was not observed when meteorology adjustment using the Cox and Chu probability distribution technique was used. However, it is unclear how to interpret either finding in the context of analysis uncertainty.

6.4 SUMMARY OF FRESNO AIR QUALITY TRENDS

Table 6-1 summarizes the findings from statistical and adjustment analyses performed on data from the Fresno area. The consensus is that ozone concentrations have declined slightly between 1987 and 1997 with little change in the 1990s. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability and meteorology was found to obscure trends.

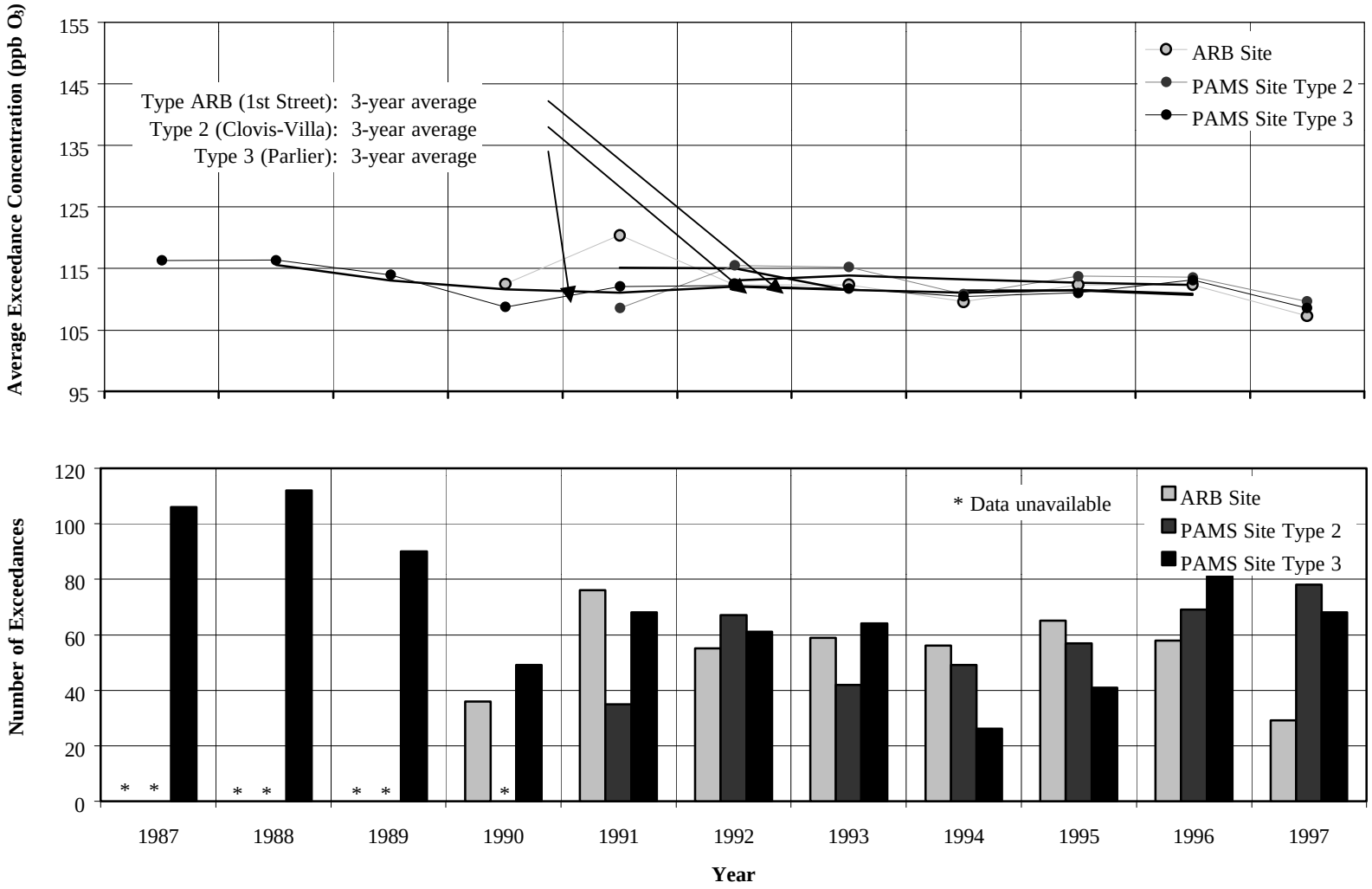

Figure 6-1. Exceedances of the California Ozone Standard at selected sites in the Fresno MSA.

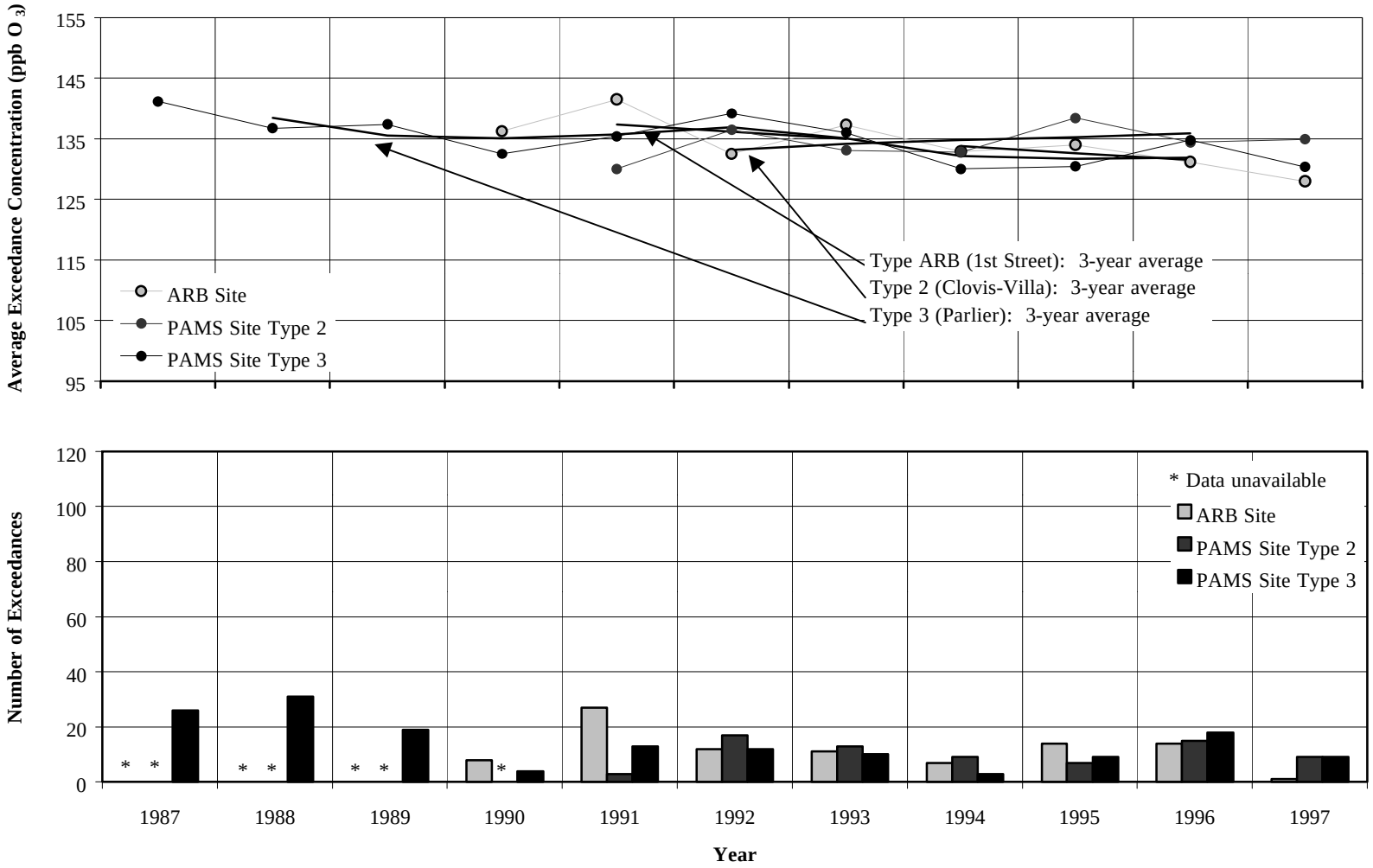

Figure 6-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the Fresno MSA.

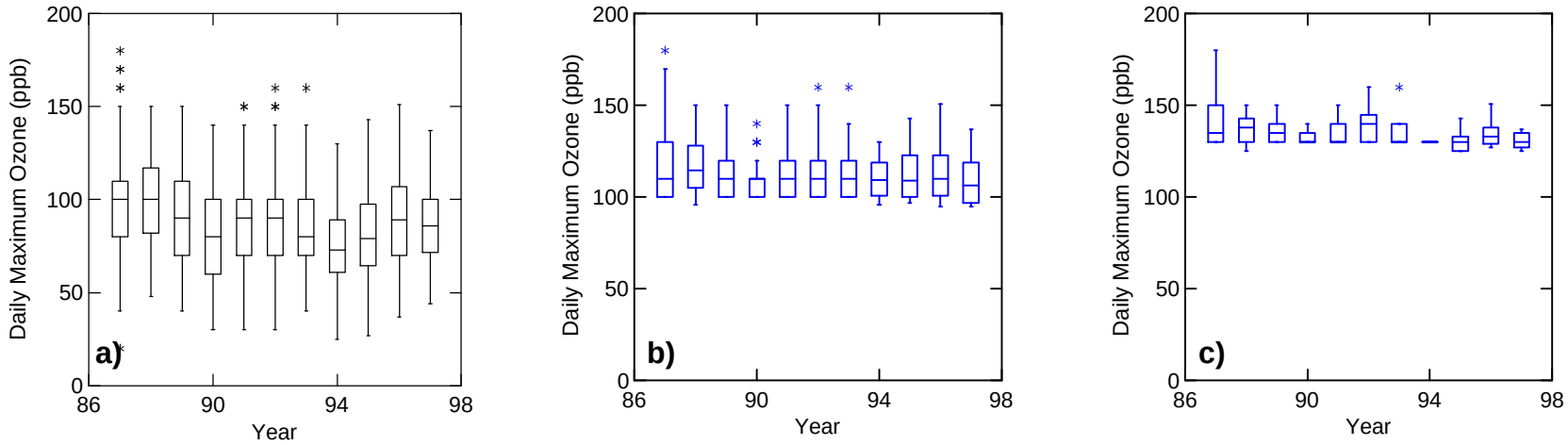

Figure 6-3. Daily maximum ozone concentrations for the Parlier site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

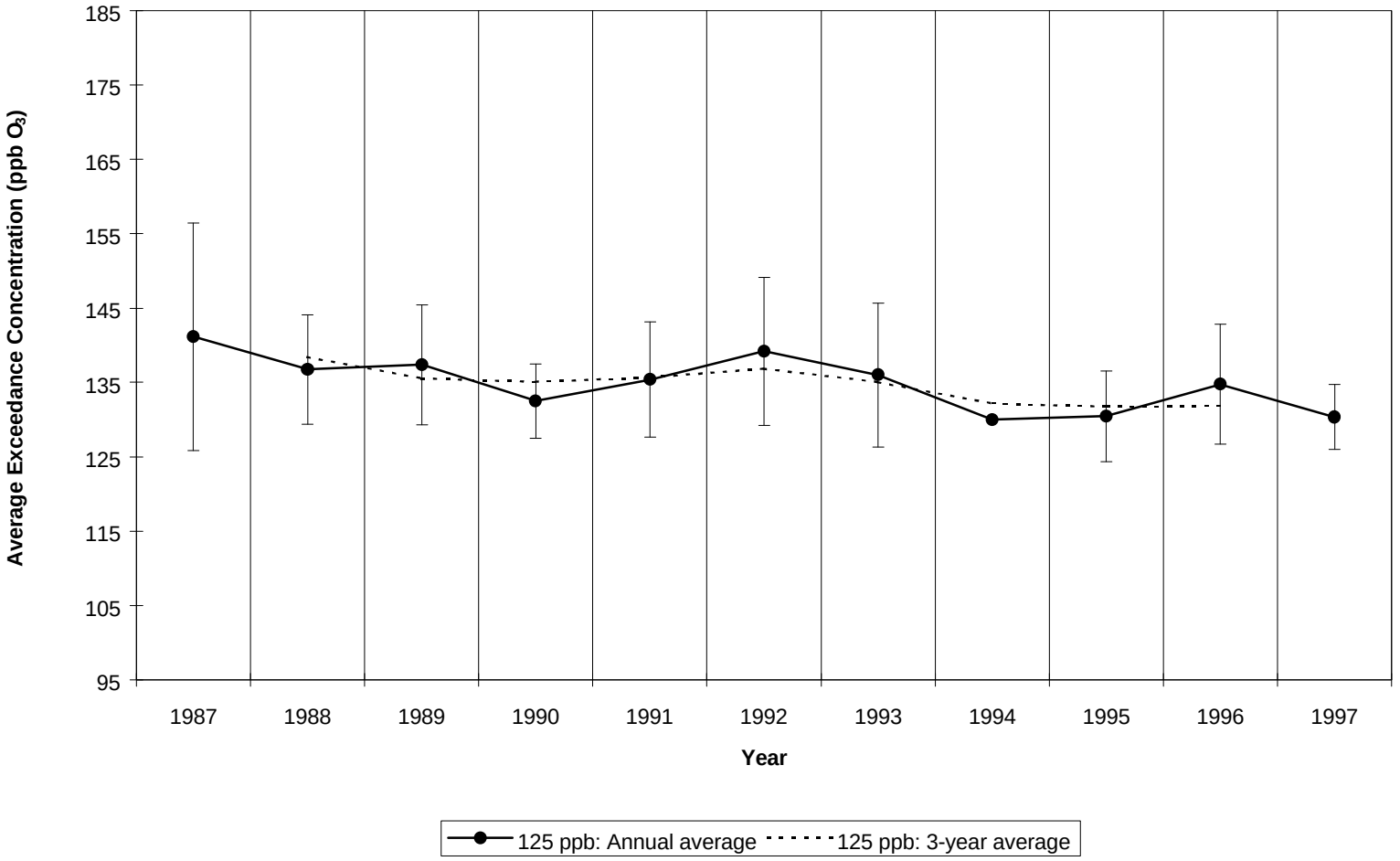

Figure 6-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty for the Parlier site. Three-year averages were determined using the highest non-exceedance ozone concentrations in 1989 and 1997 (years in which the 1-hr Ozone NAAQS threshold concentration was not reached). Error bars indicate the analysis uncertainty on the average ozone concentrations.

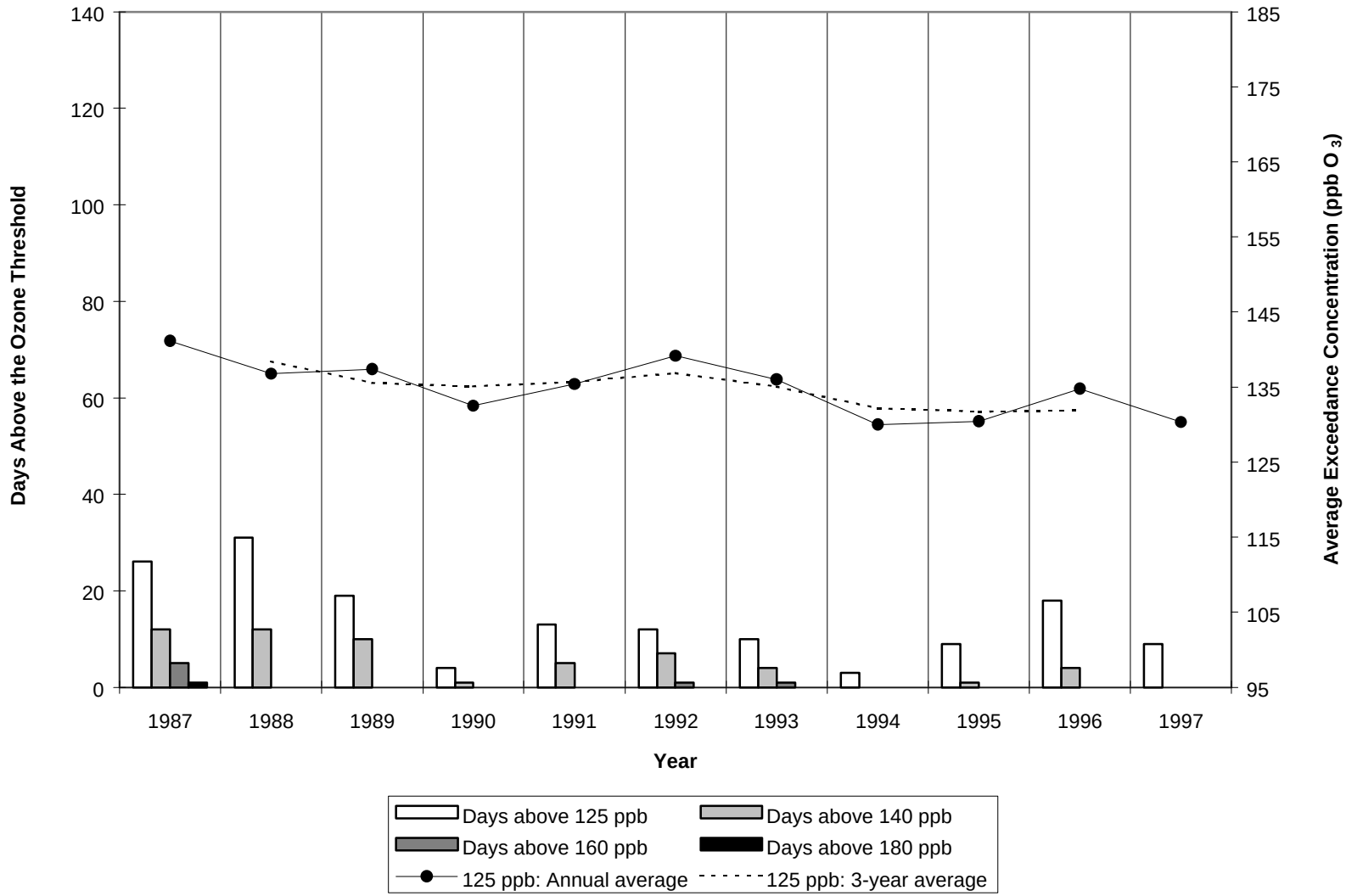

Figure 6-5. Total number of exceedances of the 1-hr Ozone NAAQS the Parlier site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

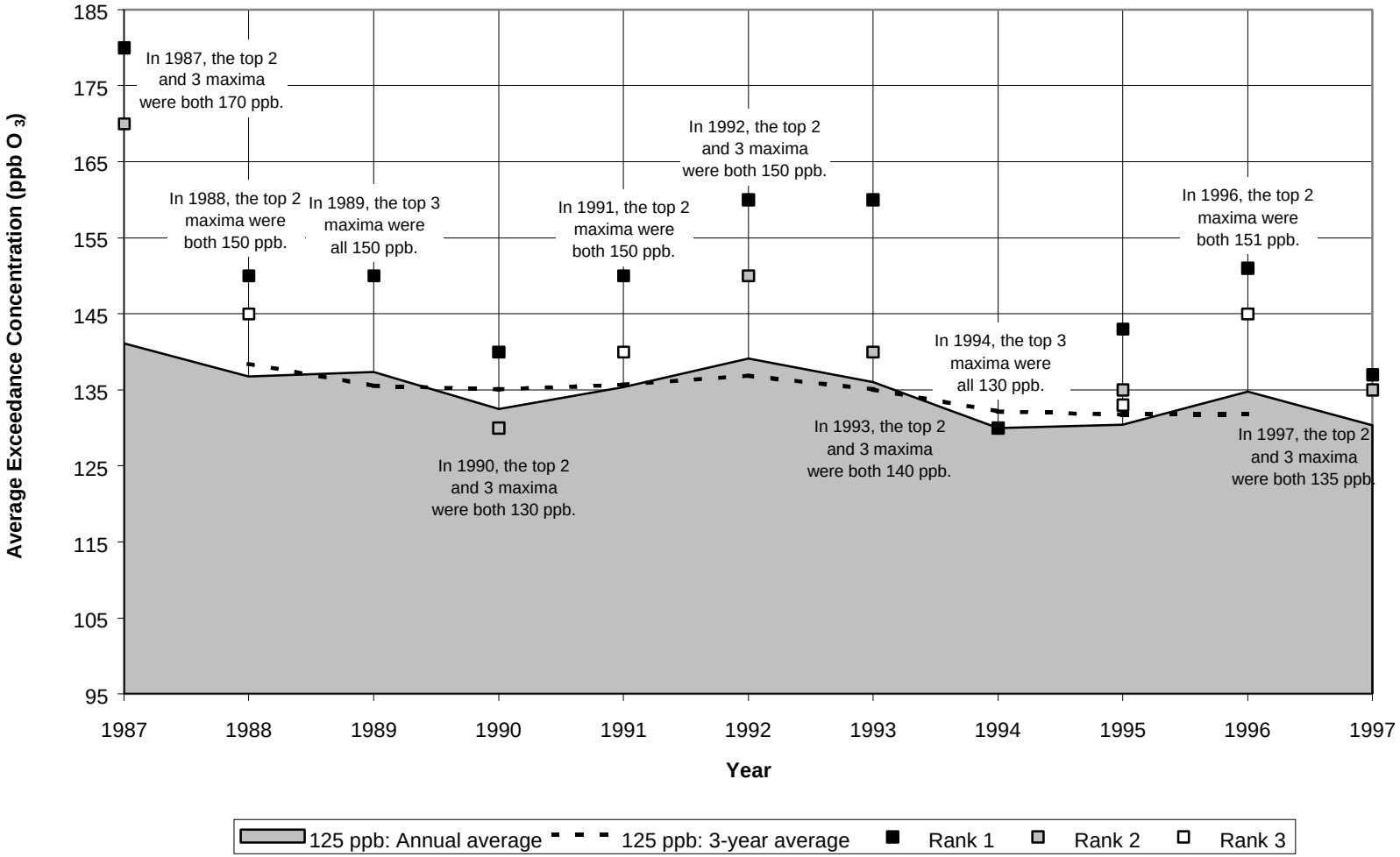

Figure 6-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS for the Parlier site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

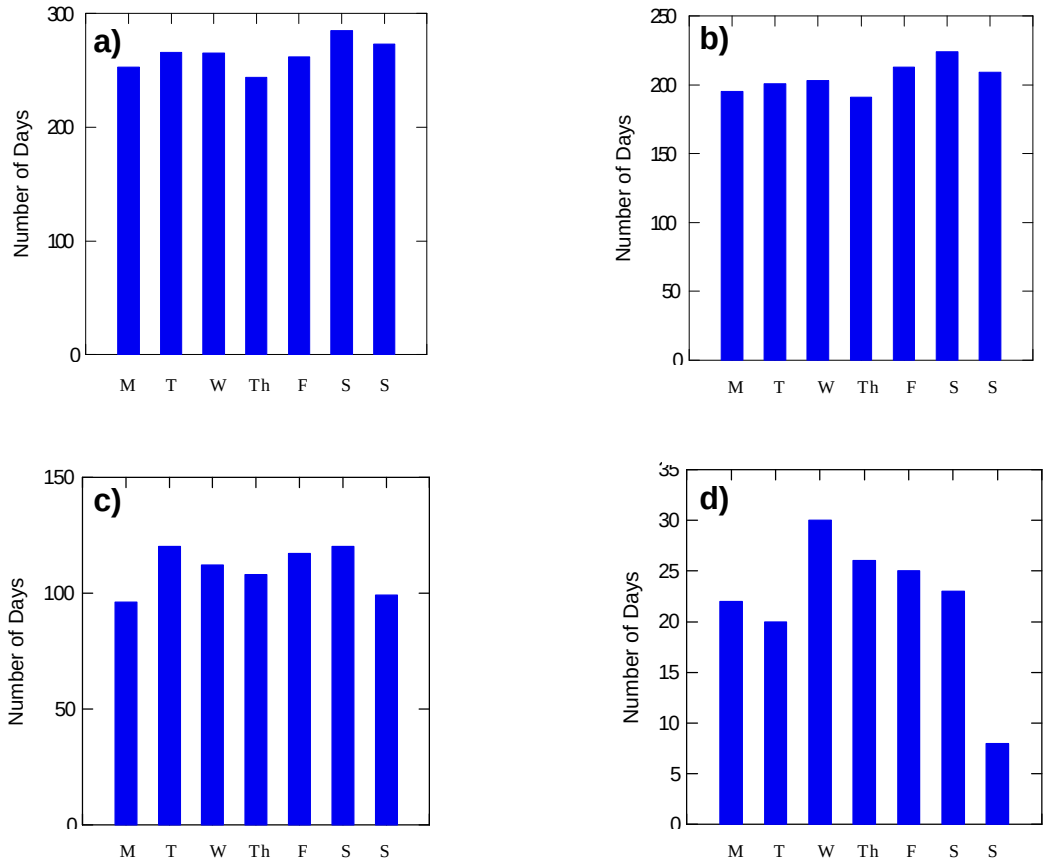

Figure 6-7. Number of days above a threshold ozone concentration by day of week for the Parlier site from 1987 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

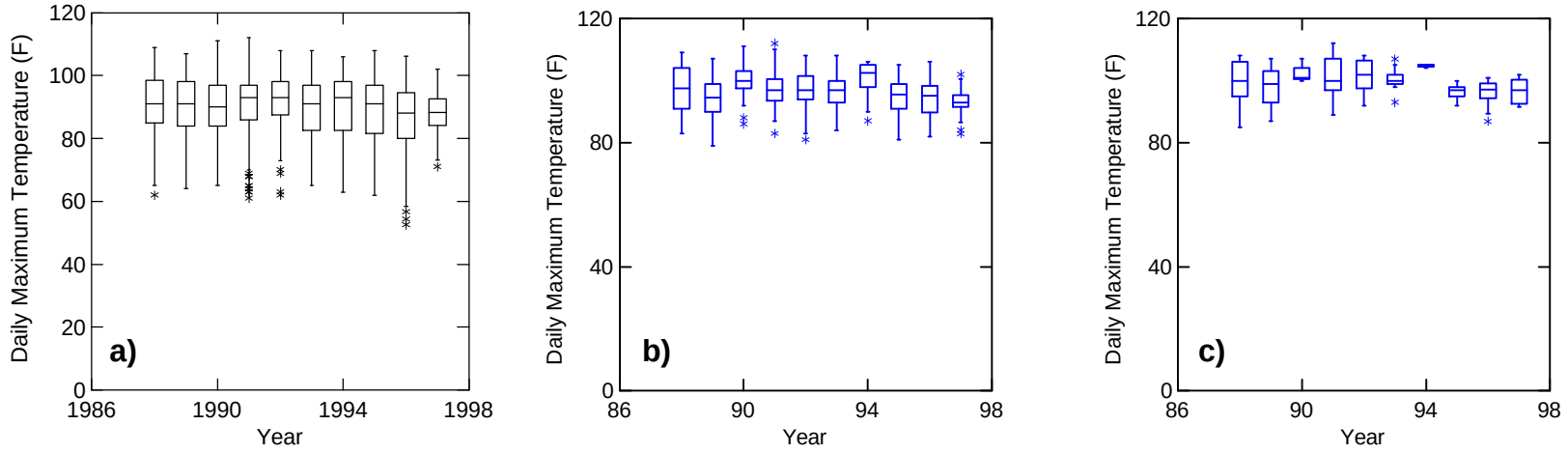

Figure 6-8. Daily maximum temperatures at the Parlier site: a) all daily maximum temperatures, b) daily maximum temperature on days when the daily maximum ozone concentrations were above the California Ozone Standard, and c) daily maximum temperature on days when the daily maximum ozone concentrations were above the 1-hr Ozone NAAQS.

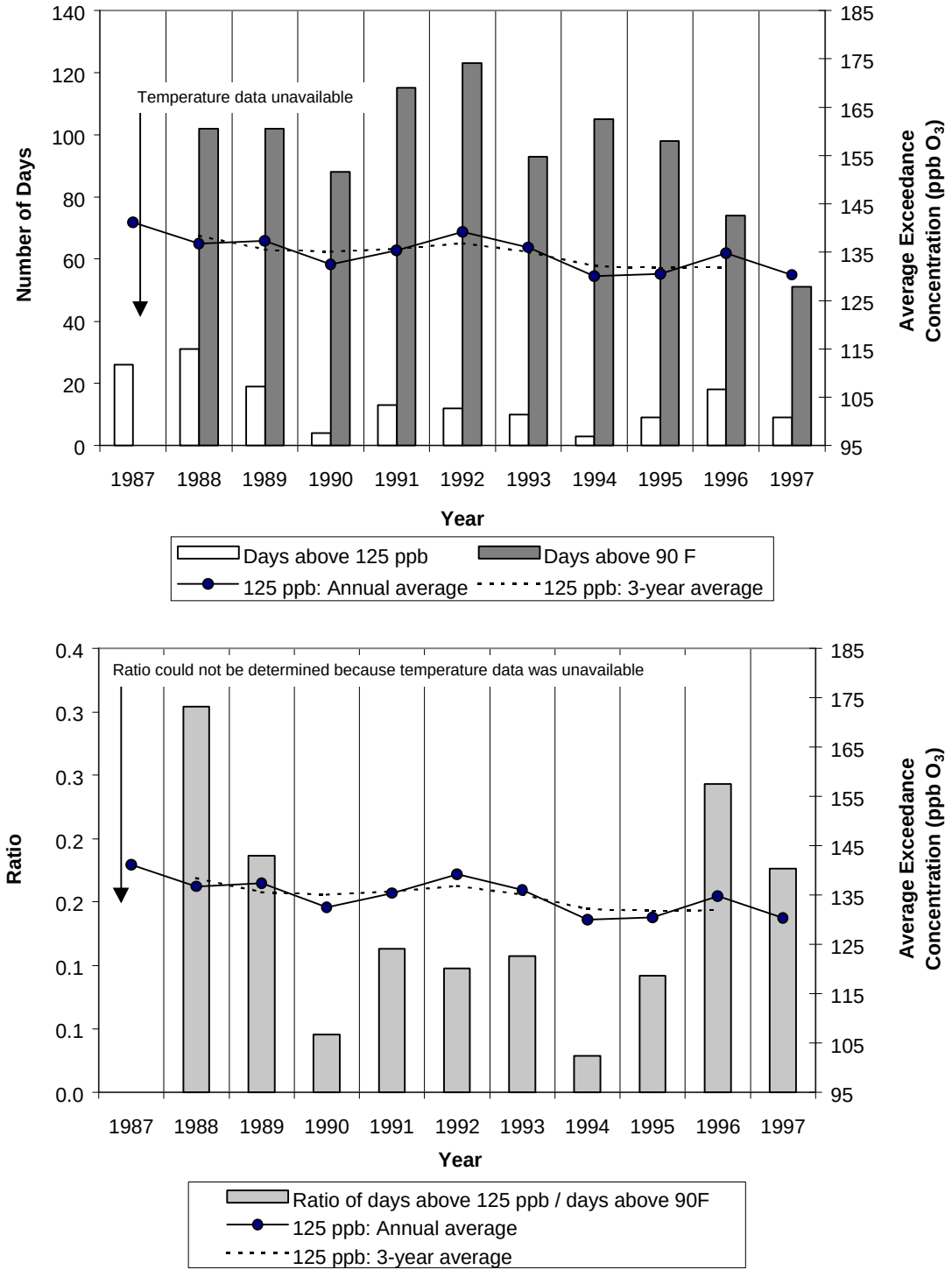

Figure 6-9. Number and ratio of the exceedances of the 1-hr Ozone NAAQS by meteorology for the Parlier site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

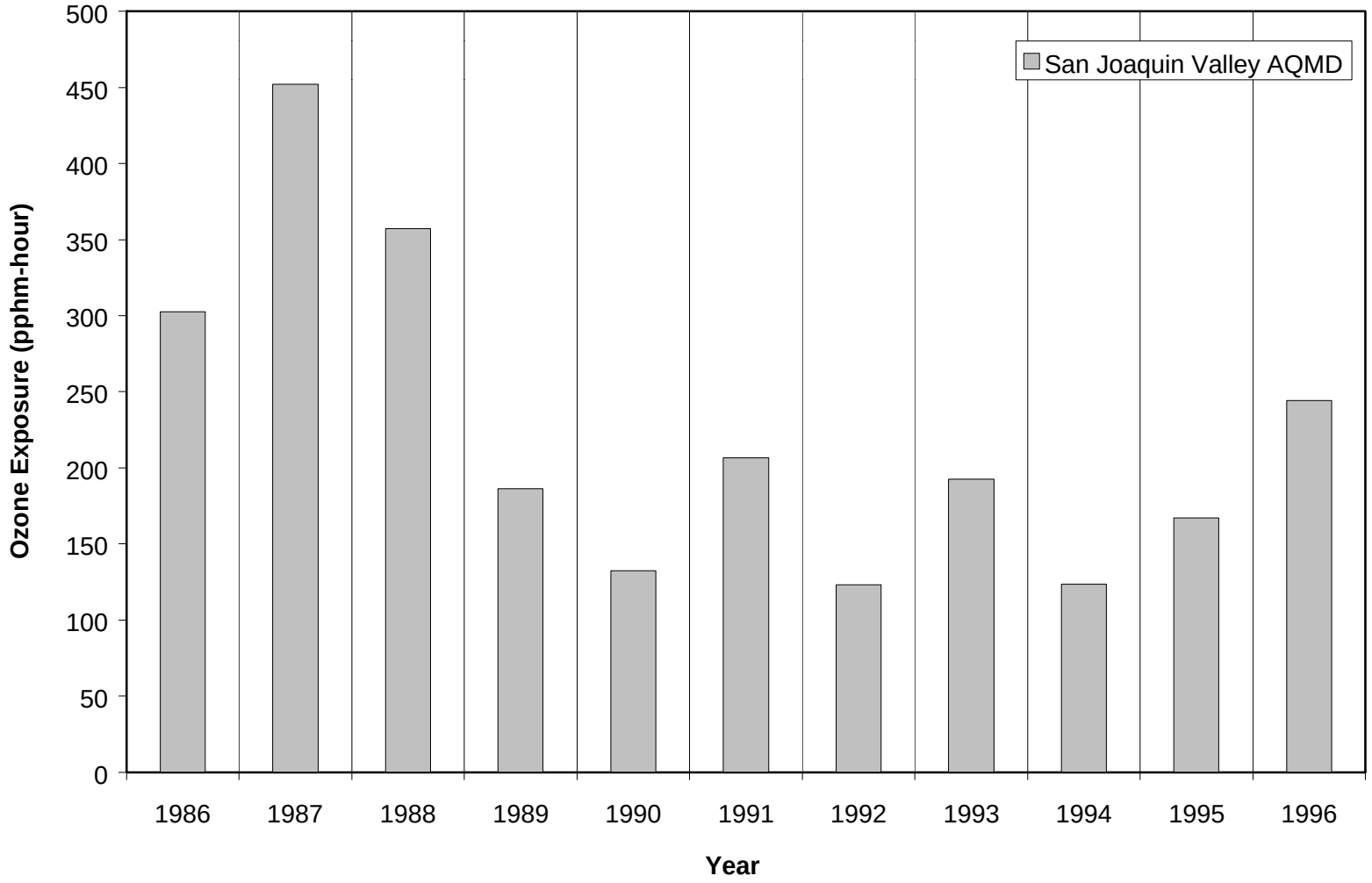

Figure 6-10. Cumulative population-weighted exposure hours of the broader San Joaquin Valley air basin to exceedances of the California Ozone Standard.

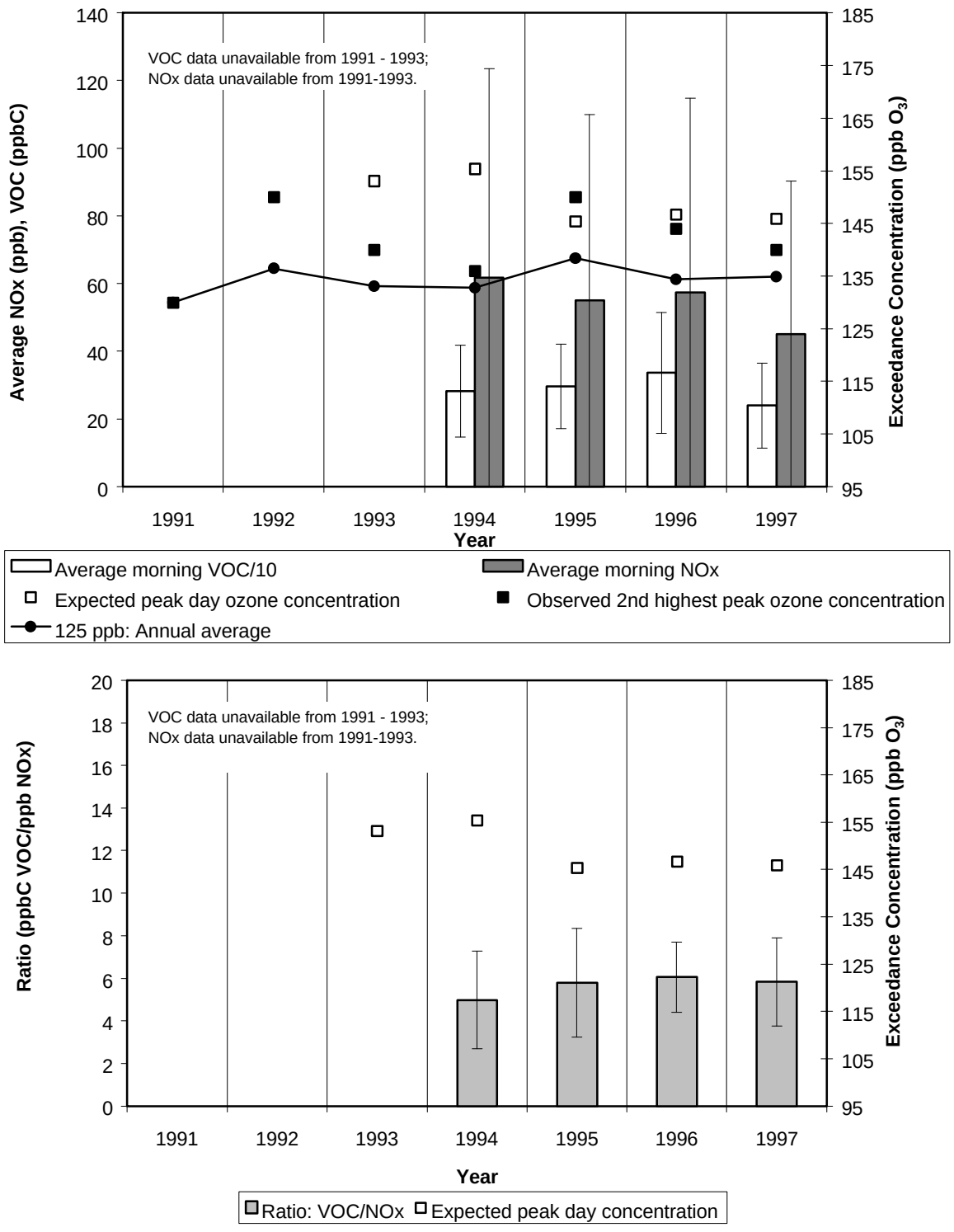

Figure 6-11. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the Parlier site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

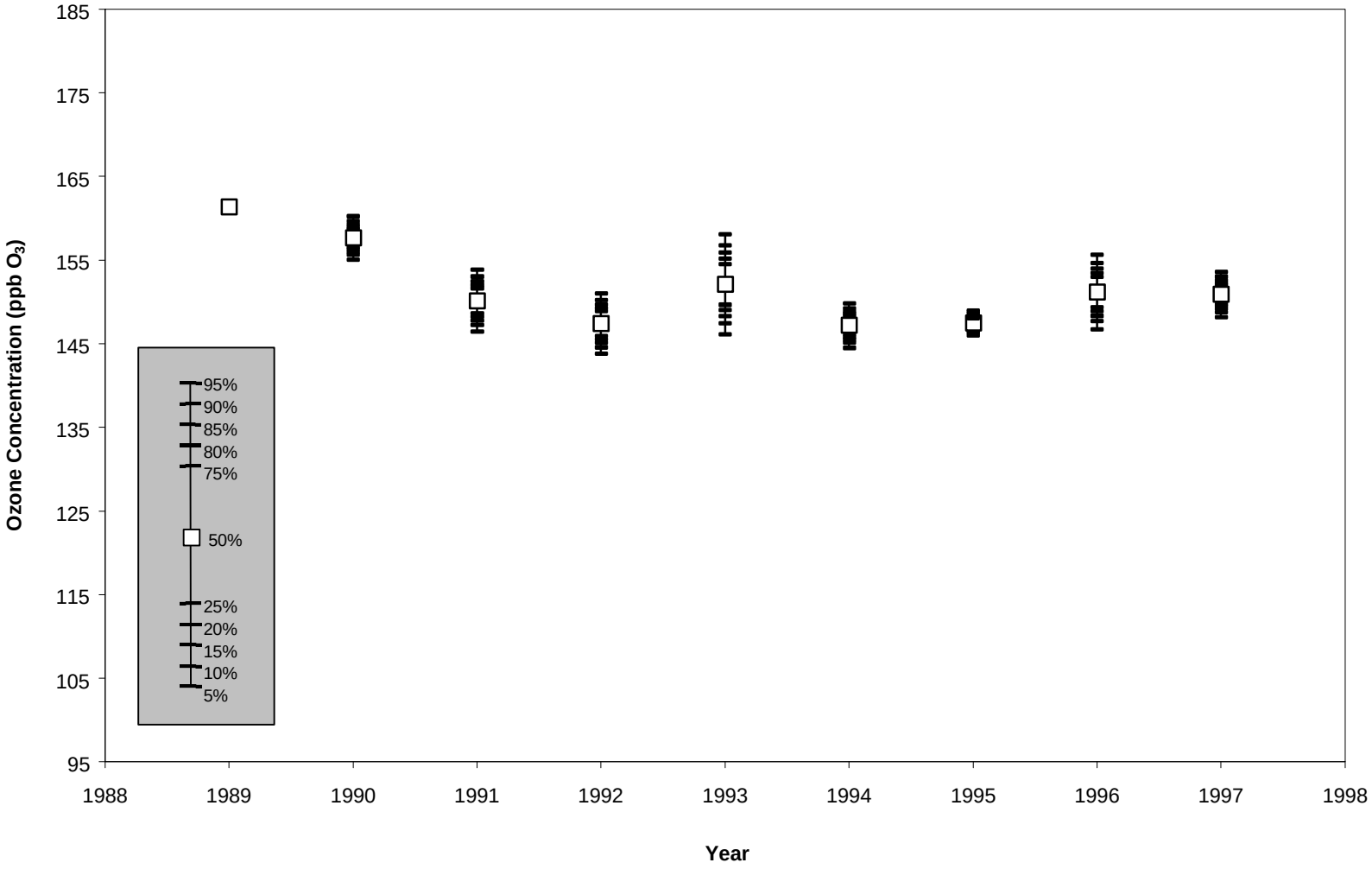

Figure 6-12. Variability of the EPDC using native variability techniques for the Parlier site.

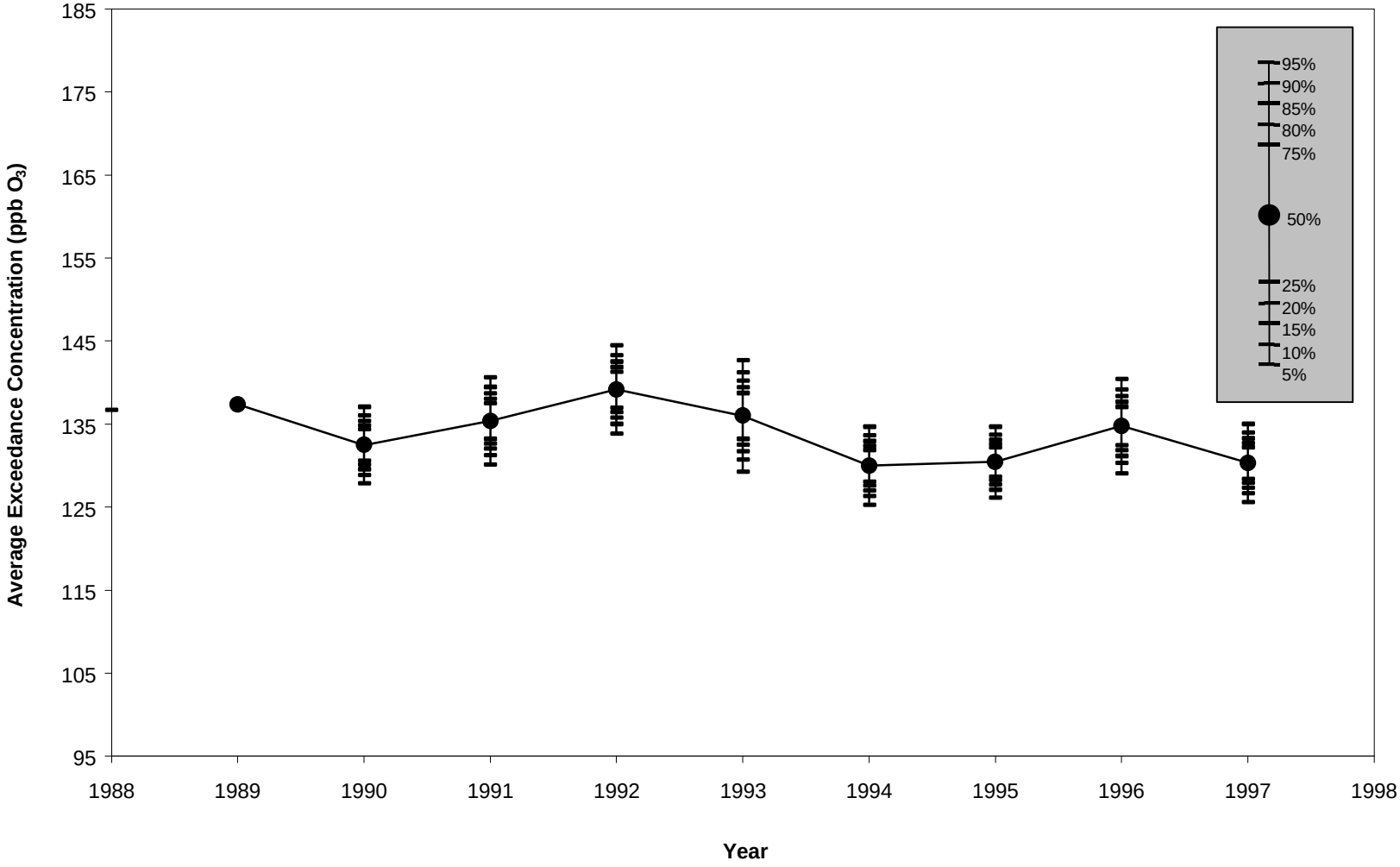

Figure 6-13. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the Parlier site.

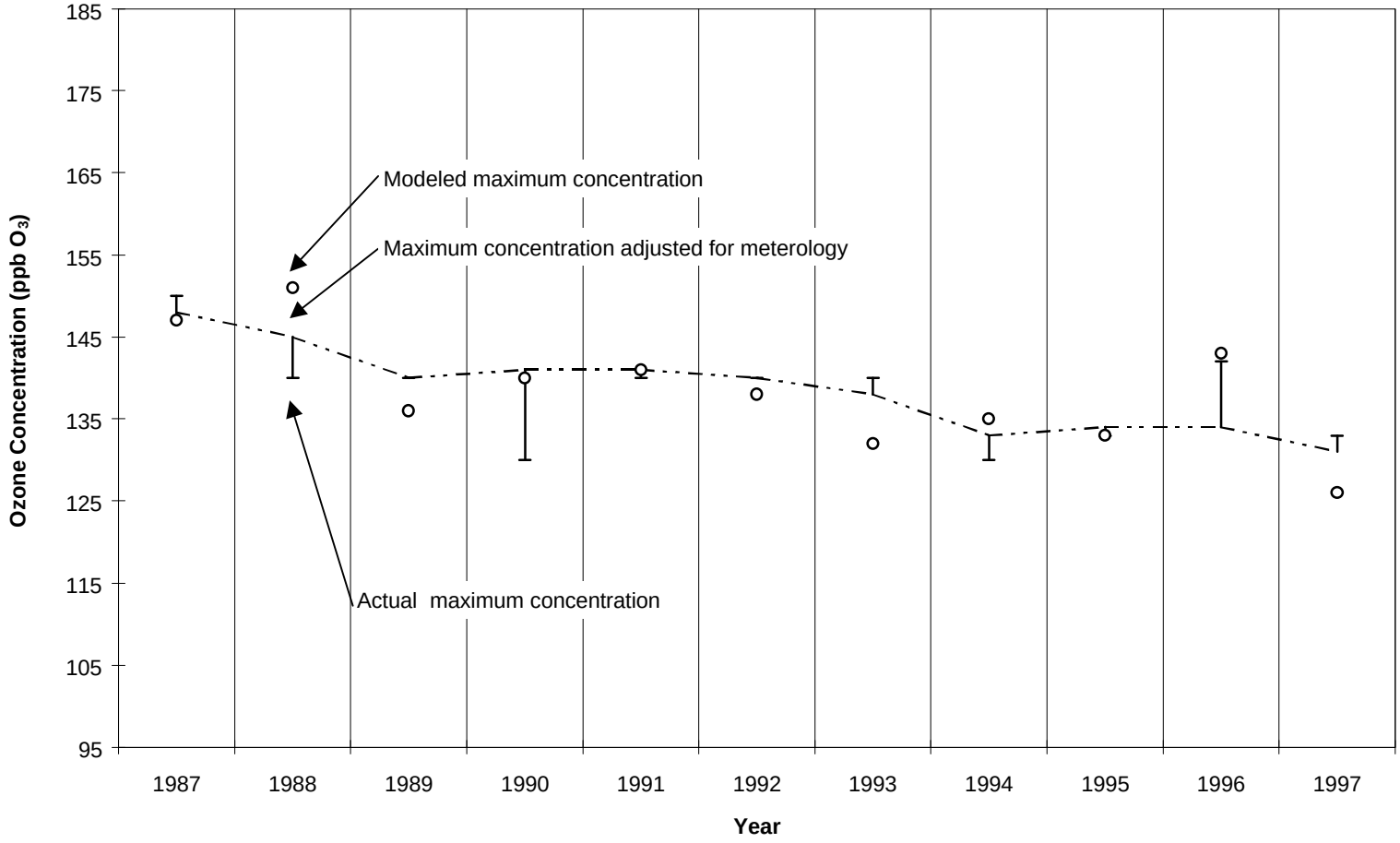

Figure 6-14. Meteorology adjustment of the maximum ozone concentrations using the Cox and Chu probability distribution technique for a site in the Fresno MSA.

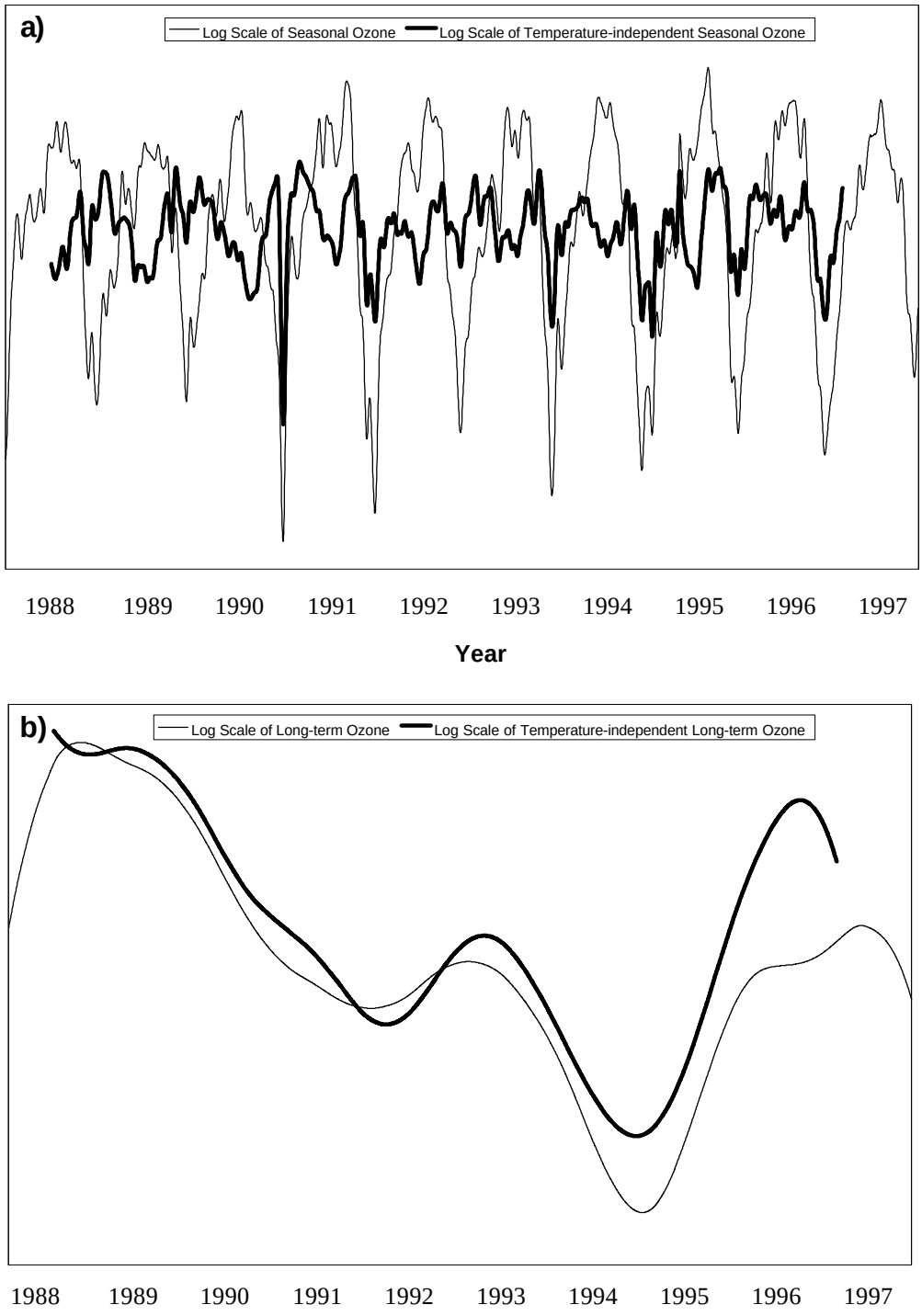

Figure 6-15. Meteorology adjustment of the Parlier site ozone concentrations using the Rao and Zurbenko filtering technique: a) seasonal component of ozone concentrations and b) long-term component of ozone concentrations (Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999).

Table 6-1. Summary of statistical and adjustment analyses performed on data from the Parlier site.

Statistical Analyses	Trend in 1987-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward Inconclusive
Running 3-yr average of exceedance concentration	Downward/Inconclusive
Total number of exceedances	Downward/Inconclusive
Spatial distribution of exceedances	Mixed, inconclusive
Maximum concentrations	Downward
Number of exceedances by meteorology	Inconclusive
Cumulative population-weighted exposure hours	Downward/inconclusive
Morning precursor concentrations	No change
Morning VOC/NO_x ratios	No change
Adjustment Analyses	**Trend in 1987-1997 Ozone**
Expected peak day concentrations	Downward
Native variability of average daily maximum ozone concentrations	Downward
Native variability of average exceedance concentrations	Inconclusive
Meteorological adjustment using probability distribution (Cox and Chu)	Downward
Meteorological adjustment using filtering techniques (Rao and Zurbenko)	Inconclusive

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7. LOS ANGELES TRENDS IN OZONE

7.1 OVERVIEW

The air quality at the PAMS Type 2-like ARB North Main Street site in Los Angeles was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1–hr Ozone NAAQS were considered in the analyses. **Figure 7-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for the site from 1987 to 1997. **Figure 7-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for the site from 1987 to 1997. These figures illustrate that there was a substantial decline in the average ozone exceedance concentration and the number of exceedances per year from 1987 to 1997.

The Los Angeles North Main Street site is an ARB long-term trend site that has characteristics similar to a PAMS Type 2 site. This PAMS Type designation identifies the site as a maximum ozone precursor emission site. The analyses involving exceedances of the 1-hr Ozone NAAQS at the Los Angeles North Main Street site are given special focus in this section; the analyses involving the California Ozone Standard at the Los Angeles North Main Street site are presented in Appendix E.

The Los Angeles North Main Street site presents several possible issues that could affect the analysis of trends:

- Change of reporting units on 12/31/93 from pphm to ppb.
- Los Angeles North Main Street site temperature measurements were unavailable in 1987 to 1989 and in 1993.
- Los Angeles Airport (Civic Center) NWS station temperature measurements were used to supplement the Los Angeles North Main Street site measurements from 1987 to 1995.
- Concurrent NO_x and hydrocarbon measurements were only available in 1991 and 1992 and from 1994 to 1997.

Several statistical analyses of the ozone air quality at these sites were performed and are discussed in this section. The analysis uncertainty is used to interpret the trends. The ARB performed a statistical analysis of the total exposure hours for the South Coast Air Quality Management District, and that analysis is also discussed in this section.

Adjustment techniques were applied to the Los Angeles North Main Street site to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was expected that the variability would add an additional uncertainty to the trend analyses. Adjustment techniques performed by other researchers for the North Main Street site (or a nearby site) are presented and discussed in order to investigate the uncertainty in the trends analysis as a function of their techniques. The findings of all the

adjustment techniques are discussed in terms of the statistical analyses (Section 7.2) to establish a consensus among the different analysis approaches.

7.2 STATISTICAL ANALYSES

The statistical analyses of the Los Angeles North Main Street site air quality revealed a dramatic improvement in the ozone air quality at the site from 1987 to 1997 as measured by the following indicators: the number of exceedance days, the highest daily maximum ozone concentration, the ratio of exceedance days to high temperature days, and the cumulative exposure hours. The analyses also identified 1993 and 1997 to be years during which the ozone concentrations were significantly lower at the Los Angeles North Main Street site and a larger number of the exceedances occurred on Saturday and Sunday. Some statistics did not reveal clear trends and were also subject to large analysis uncertainties, including the average exceedance concentration and the 3-yr running average exceedance concentration.

7.2.1 Average exceedance concentration

Figure 7-3 shows the distribution of the daily maximum ozone concentrations at the Los Angeles North Main Street site from 1987 to 1997. Figure 7-3 demonstrates that the bulk of the daily maximum ozone concentrations that occurred at the site in 1993 and 1997 were lower than previous years and that there are fewer outlier points and smaller ranges in the bulk of the ozone concentrations from 1993 to 1997. These findings suggests that near compliance with the standard is more commonplace. Figure 7-3a shows that the bulk of the daily ozone concentrations (i.e., interquartile range) were below the 1-hr Ozone NAAQS threshold concentration and that the median ozone concentrations exhibit a slightly decreasing trend over the entire time period at this site.

Figure 7-4 shows the average exceedance concentrations at the Los Angeles North Main Street site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in the previous figure are not distinguishable when the analysis uncertainty of the exceedance concentrations is considered. However, a slight reduction in the average concentration of the exceedances of the 1-hr Ozone NAAQS is observable in 1991, 1993, and 1996; there were no exceedances of the NAAQS in 1997. The 1993 and 1997 declines in concentration appear to follow the trend that is observable at many of the other selected PAMS sites in California.

7.2.2 Running 3-year average of exceedance concentration

The running 3-year average concentrations of the 1-hour Ozone NAAQS exceedances are shown in Figure 7-4. The figure illustrates that the average exceedance concentrations gradually decline from 1987 to 1997 when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period. However, the decreasing ozone concentrations are within the magnitude of the analysis uncertainty (i.e., standard deviation of

the average exceedance concentrations). Therefore, decreases in the ozone concentrations are unclear.

7.2.3 Total number of exceedances of the standard

Although the average exceedance concentration was not observed to change dramatically from the late 1980s to the late 1990s, the number of exceedance days has definitely decreased. **Figure 7-5** demonstrates this point. The figure demonstrates that the numbers of exceedances associated with both high (above 180 ppb) and low (above 125 ppb) daily maximum ozone concentrations have decreased from 1987 to 1997. Exceedance concentrations above 180 ppb were uncommon after 1992. Figure 7-5 also demonstrates that an uncommonly small number of exceedances of the 1-hr Ozone NAAQS were experienced in 1993 and that a smaller number of these exceedances were associated with ozone concentrations above 125 ppb, 140 ppb, or 160 ppb.

7.2.4 Identification of the highest exceedance concentrations

Figure 7-6 presents the top three exceedance concentrations experienced at the Los Angeles North Main Street site. This figure illustrates that the highest daily maximum ozone concentration each year has decreased substantially from 1987 to 1997. This figure also demonstrates that the highest exceedance concentrations were closer to the average exceedance concentration during the years with fewer exceedances (e.g., 1993 and 1995 to 1997). The highest exceedance concentrations were much greater than the average exceedance concentrations during years with more exceedances and higher average exceedance concentrations (e.g., 1987 to 1992). This suggests that the years with fewer exceedances and lower exceedance concentrations are more representative of typical (i.e., average) air quality at the Los Angeles North Main Street site.

7.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated (**Figure 7-7**), a larger number of exceedances were observed on Saturday and Sunday for all threshold concentrations. However, when the exceedances are examined by day of week and by year, no apparent trend is discernable. This suggests that, statistically, there is a greater chance for exceedances of the 1-hr Ozone NAAQS on Saturday and Sunday, but the likelihood of an exceedance on these days has not changed over the years.

7.2.6 Number of exceedances of the standard by meteorology

Temperature measurements were made at the Los Angeles North Main Street site from 1990 to 1992 and from 1994 to 1997. Because the temperature measurements were discontinuous and did not span the time period for which ozone measurements were available,

Los Angeles North Main Street site temperature measurements were supplemented with measurements made at the NWS station at the Los Angeles Airport from 1988 to 1995. The temperature measurements at the Los Angeles North Main Street site and the Los Angeles Airport NWS station demonstrated excellent correlation for the years of concurrent temperature measurements. The correlation plot is presented in Appendix A. The subsequent analyses involving temperature measurements use the supplemented data set.

Figure 7-8 presents the distribution of the daily maximum temperatures from 1988 to 1997. The figure shows that the bulk of the daily maximum temperatures (i.e., interquartile range) were not statistically different on the exceedance days than during all of the summertime days. For the 1-hr NAAQS, slightly lower temperatures are associated with the exceedances in 1991, and elevated temperatures are associated with the exceedances in 1995. This analysis suggests that the meteorology (with temperature as an indicator of meteorology in general) was not atypical of the average summertime meteorology at the Los Angeles North Main Street site on exceedance days.

Figure 7-9 shows a bar graph of the number of days above the ozone standard and the number of days above 90°F for 1987-1997 and a bar graph of the ratio of the number of days above the ozone standard and the number of days above 90°F. The plots also show the annual average exceedance concentrations and 3-yr running averages of the exceedance concentrations. These plots demonstrate that the ratio of the number of days above the 1-hr Ozone NAAQS and the number of days above a maximum daily temperature of 90°F have decreased dramatically from 1988 to 1997. Prior to 1990, there were more days with ozone exceedances than days above 90°F. After 1992, the reverse is true; there are more days above 90°F than there are ozone exceedances. Notably, the fewest exceedances of the 1-hr Ozone NAAQS occurred from 1994 to 1997. This suggests that the number of exceedance days decreased over the entire time period, regardless of differences in meteorology. One could further speculate that changes in ozone precursor emissions have contributed to the declining ozone concentrations.

7.2.7 Cumulative population-weighted exposure hours

Figure 7-10 shows an estimate of the cumulative population-weighted number of hours that the SCAQMD is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1998. This statistic consolidates into a single indicator the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances.

This broader perspective on air quality suggests that ozone exposure in the broader South Coast area has dramatically decreased since 1986. This finding is consistent with prior analyses of the average exceedance concentration indicator at the Los Angeles North Main Street site. The exposure calculations have not been compiled for 1997 yet. The analysis suggests that air quality in the South Coast area has improved from the late 1980s to the late

1990s. However, a statistical evaluation of the exposure-hours was not available to assess the errors on the analysis.

7.2.8 Exceedance concentrations as a function of early morning precursor concentrations

Figure 7-11 illustrates that the exceedance concentrations are not clearly related to the average early morning NO_x and VOC concentrations. The average exceedance concentrations decrease slightly from 1987 to 1997 (see Section 7.2.1). The second highest daily maximum ozone concentrations decrease over the time period, but the concentration in 1993, for which VOC measurements are unavailable, is atypically low. The average precursor concentrations do not change significantly over the time period. However, a notable change occurred in the ratio of average early morning NO_x and VOC measurements from 1991 to 1992 and a reduction in the ratio of average precursor measurements from 1994 to 1997. The average ratios appear to be in the VOC-limited regime, suggesting that reductions in VOC concentrations could result in lower maximum ozone concentrations. This suggests that the change in observed second highest maximum ozone concentrations that occurred in the mid-1990s might be related to the decreased ratio of precursor concentrations. This is consistent with the meteorology analysis (Section 7.2.6) that suggests that changes in meteorology were not responsible for decreased ozone concentrations in 1994 and 1997.

7.3 ADJUSTMENT ANALYSES

Statistical analyses applied to the Los Angeles North Main Street site did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques applied to the ozone measurements made at the Los Angeles North Main Street site and discussed in this section are used to assess whether the uncertainty analysis is, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques were used to estimate the uncertainty in the ozone measurements as a result of atmospheric or meteorological variability from 1987 to 1997 and differences in meteorology from year to year. It is anticipated that the adjustment techniques will allow for more clear trends to be determined.

7.3.1 EPDCs as a function of early morning precursor concentrations

Figure 7-11 illustrates that the EPDCs are related to the ratio of the average early morning NO_x and VOC precursor concentrations. This finding is consistent with the analysis performed in Section 7.2.8, which suggests that reductions in the second highest peak ozone concentrations were related to reductions in the ratio of the average early morning precursor concentrations in the mid to late 1990s.

The EPDCs followed a similar trend as the second highest peak ozone concentrations and decreased steadily from 1989 to 1997. The ratio of average early morning NO_x and VOC precursor concentrations decreased from 1992 to 1994 but was fairly level from 1994 to 1997.

This suggests that the decreased ratio of precursor concentrations had an effect on the observed maximum ozone concentration in the mid to late 1990s (in terms of the EPDC). Notably, the EPDC continued to decrease even when the ratios did not (e.g., 1995 to 1997). However, it is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This is observed in this case where the EPDC in 1993, 1996, and 1997 are much different from the observed second highest maximum ozone concentrations.

7.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis as a result of atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this report, the concept of native variability was also applied to average daily maximum ozone concentrations. This will allow a direct comparison between the analysis uncertainties and the uncertainties resulting from atmospheric and meteorological variability.

Figure 7-12 demonstrates the native variability about the EPDC. When 95 percent confidence limits are associated with the native variability estimates, significant reductions in ozone concentrations are seen from 1995 to 1997. This is consistent with the cumulative population-weighted exposure hour statistical analysis that suggested that ozone concentrations have decreased from the late 1980s to the late 1990s. Notably, the native variability estimates on the EPDC suggest that dramatic changes in ozone concentrations did not occur until 1995. This is contrary to all prior analyses. This analysis does support the finding that the reduction in ozone concentrations from the late 1980s to the late 1990s is statistically viable. This analysis also suggests that the ozone concentrations were higher in 1990 than they were in the late 1980s. It is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This analysis also applies native variability principles to EPDCs and is therefore also biased against anomalous events on both sides of the spectrum.

Figure 7-13 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS. The ozone trends are obscured when native variability estimates are considered, as they were when the analysis uncertainties were considered. When 95 percent confidence limits are considered, the ozone concentrations do not show a significant change. Only in 1997 is a decrease revealed in ozone concentrations that is greater than the native variability on the average concentration. This suggests that there were no changes in the ozone concentrations from 1987 to 1996, because the changes were within the uncertainty due to the native variability of the average ozone concentration. This analysis also suggests that the average ozone concentrations were higher than they were in the early 1980s during most years (e.g., 1990, 1992, and 1994). Finally, the finding of this analysis is consistent with the findings that were suggested when the native variability of EPDC was considered.

7.3.3 Meteorology adjustment using the Cox and Chu probability distribution technique

Figure 7-14 shows the maximum daily ozone concentrations that have been adjusted to account for meteorology with a confidence limit of 95 percent by Cox and Chu (1998). This figure suggests a decreasing trend in ozone concentrations that is consistent with the EPDC estimates. This analysis was performed for a site that was in the Los Angeles MSA, although the specific site location is unknown. Because the high ozone concentrations in 1989, 1991, 1992, and 1994 are not observed at the site that is the basis of this analysis, these findings should not be used to determine absolute concentrations for the adjusted ozone concentrations.

The figure shows the actual maximum ozone concentrations, the modeled maximum ozone concentrations, and the adjusted maximum ozone concentrations. The modeled concentrations indicate how well the Weibull distribution fit the daily maximum ozone concentrations (e.g., in 1987 and 1995), the model did not capture the observed daily maximum ozone concentrations well). The adjusted concentrations are adjusted from the modeled concentrations. They represent the modeled concentration that would be likely if the temperature, wind speed, and wind direction conditions within a particular year were identical to the average meteorological conditions.

When the daily maximum ozone concentrations are adjusted for meteorology, the trend in ozone concentrations appears to decrease. High ozone concentrations are lowered (e.g., 1987), and low ozone concentrations are raised (e.g., 1992, 1994 and 1995) using this smoothing technique. These findings make sense as meteorology can have both positive and negative effects on ozone formation. Finally, it is expected that the Cox and Chu method will bias against both high and low ozone concentrations that do not fit well to the probability distribution. This is demonstrated in 1987, 1990, 1992, 1994 and 1995, when the modeled ozone concentrations are dramatically different than the actual (i.e., observed) ozone concentrations. Surprisingly, the unusually low ozone concentration that was observed in 1997 fit the Weibull distribution well.

7.3.4 Meteorology adjustment using the Rao and Zurbenko filtering technique

At our request, the Kolmorov-Zurbenko filtering technique was applied to the North Main Street daily maximum ozone concentrations by a coworker of Dr. Rao, Steven Porter. **Figure 7-15** presents Mr. Porter's results for the maximum daily ozone concentrations that have been separated into two time scales of ozone variability and adjusted to filter out the effects of temperature (personal communication with Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999). Temperature was the sole surrogate for meteorology in this analysis. The adjusted ozone concentrations reveal a variable trend that is due to other long-term meteorological parameters (besides temperature) or policy and economic changes that have caused emissions changes to the MSA.

Figure 7-15a illustrates that seasonal variability in temperature had a dramatic impact on the observed ozone concentrations (i.e., 64 percent of the ozone concentrations are explained by the normal seasonal variations in meteorology). However, 36 percent of the

seasonal ozone concentrations is not explained by temperature. This finding indicates that other meteorological parameters not used in this analysis are important to ozone formation in the Los Angeles MSA. Some other possible parameters include latitude, longitude, elevation, station pressure, aerosol optical depth coefficients, terrain factors, monthly vertical ozone column depth, monthly albedo factor, total cloud cover, total opaque cloud cover, and precipitable water vapor.

Figure 7-15b illustrates that the long-term reduction in ozone concentrations was substantially influenced by temperature during several years (e.g., 1988, 1989, 1990, and 1997). However, on the whole, only 2 percent of the variability in long-term ozone concentrations was explained by temperature. This suggests that some other atmospheric event was responsible for the decreasing ozone concentrations on this time scale, such as variability in a different meteorological parameter, emissions, or economic factors. This figure is interesting because it suggests that the high ozone concentrations that were observed in 1988, 1989, and 1991 were substantially influenced by long-term variations in temperature. Further, a clearly downward trend in daily maximum ozone concentrations is not discernible using this technique as it was when the Cox and Chu meteorological adjustment technique was used. Substantial reductions in adjusted ozone concentrations are also not discernible in 1997 because the EPDC with native variability estimates technique was used. However, it is unclear how to interpret either of the findings in the context of analysis uncertainty. It is likely that other meteorological factors are required to better filter the ozone data.

7.4 SUMMARY OF LOS ANGELES AIR QUALITY TRENDS

Table 7-1 summarizes the findings from statistical and adjustment analyses performed on data from the Los Angeles North Main Street site. The consensus is that ozone concentrations at this site have declined significantly between 1987 and 1997. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability and meteorology was found to obscure trends.

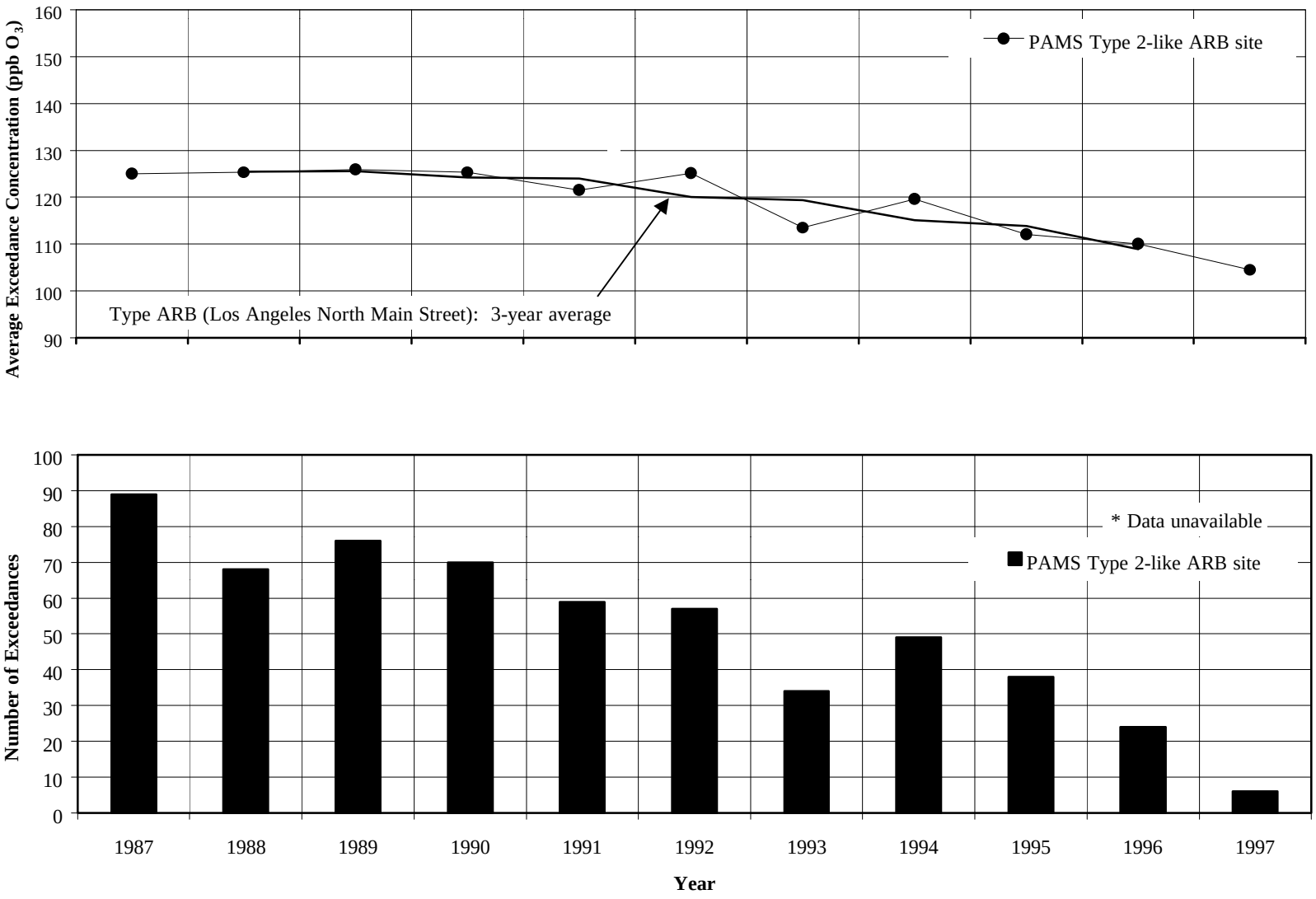

Figure 7-1. Exceedances of the California Ozone Standard at selected sites in the Los Angeles MSA.

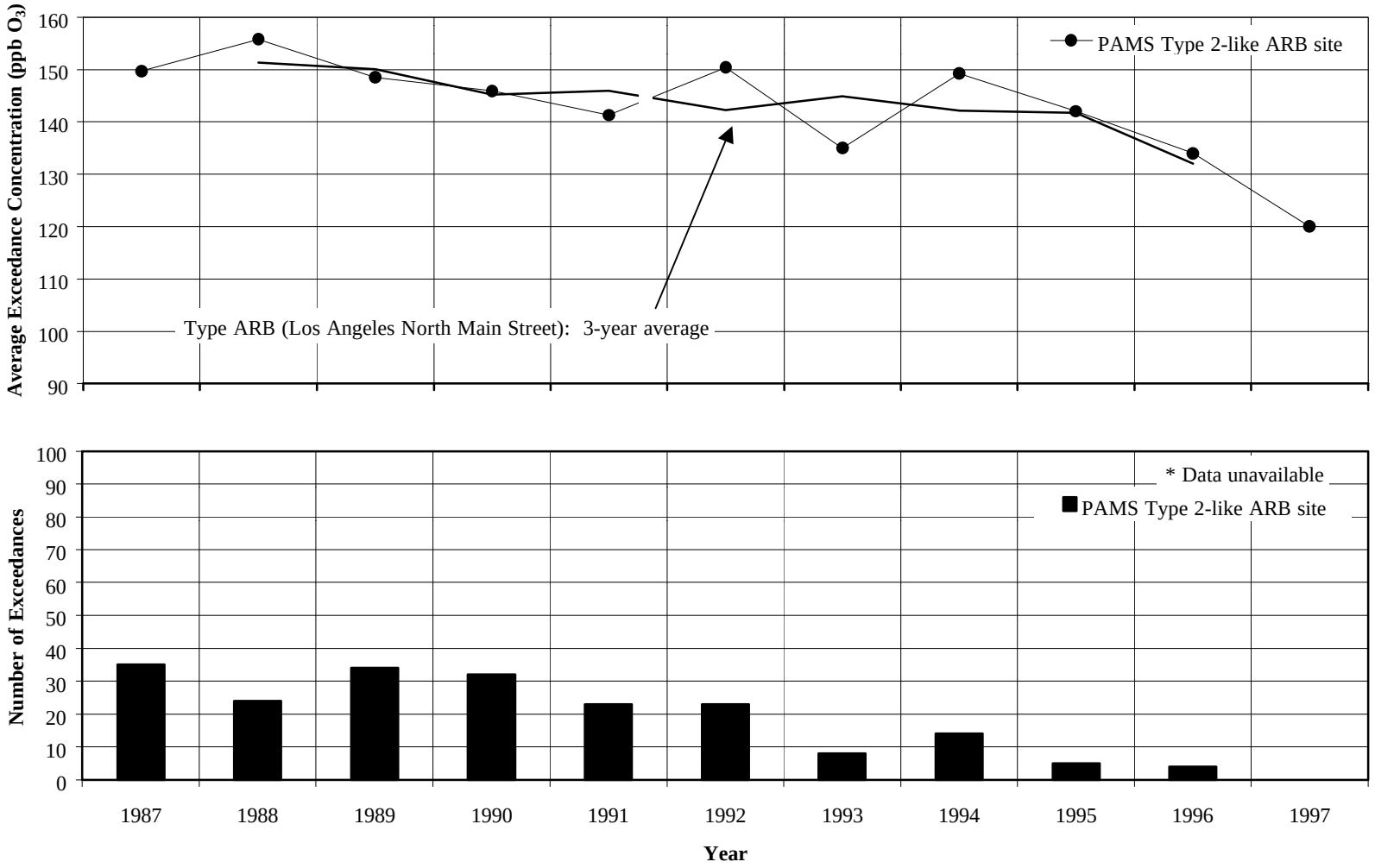

Figure 7-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the Los Angeles MSA. Averages were determined using the highest non-exceedance concentrations in 1997.

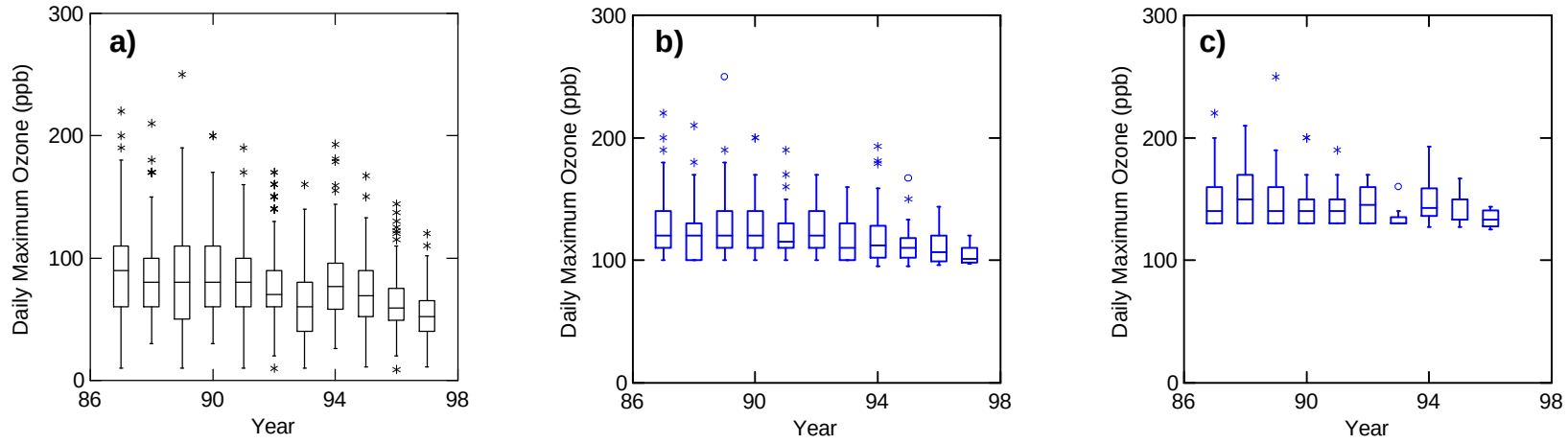

Figure 7-3. Daily maximum ozone concentrations for the Los Angeles North Main Street site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

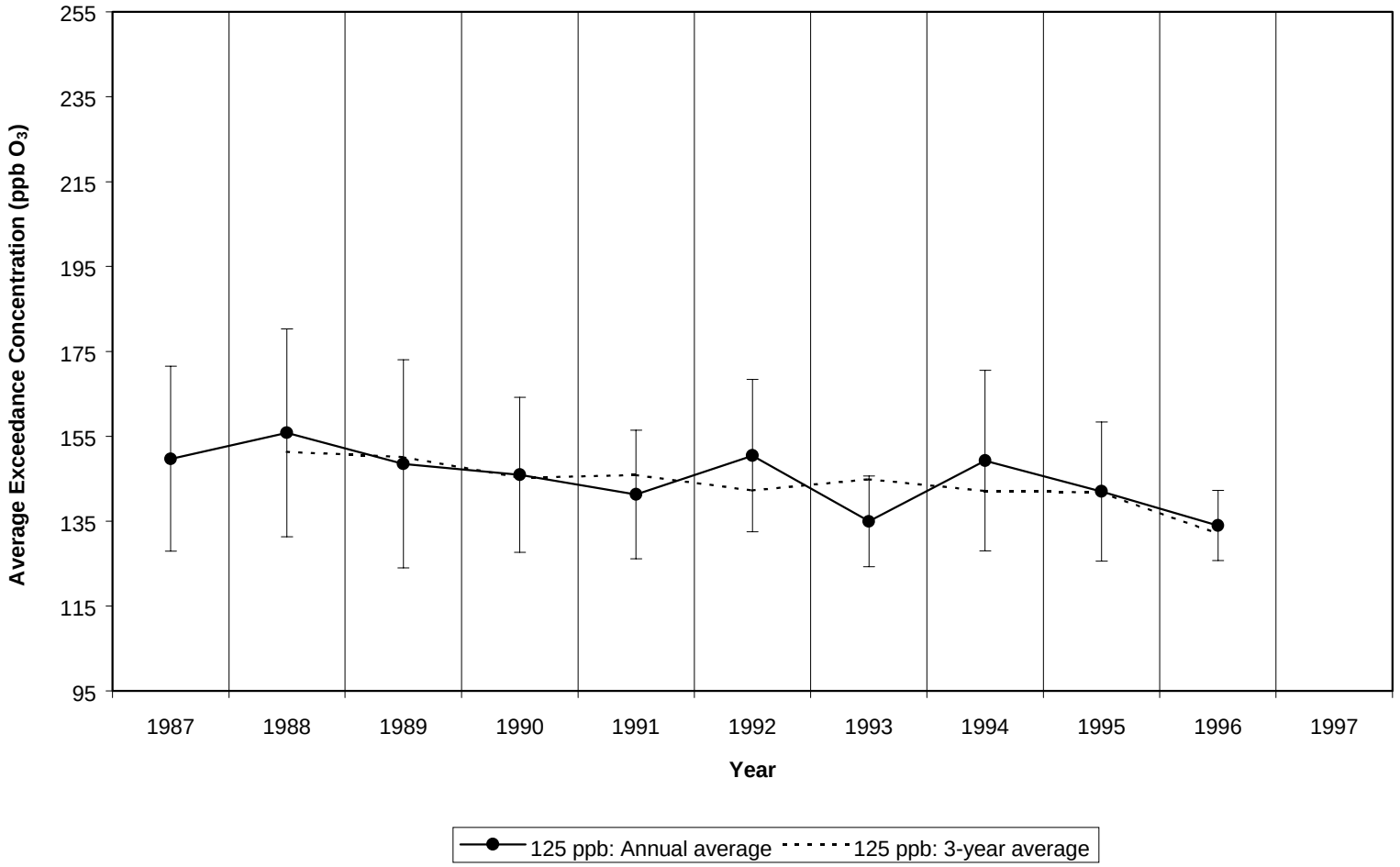

Figure 7-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty for the Los Angeles North Main Street site. Three-year averages were determined using the highest non-exceedance ozone concentrations in 1997 (year in which the 1-hr Ozone NAAQS threshold concentration was not reached). Error bars indicate the analysis uncertainty on the average ozone concentrations.

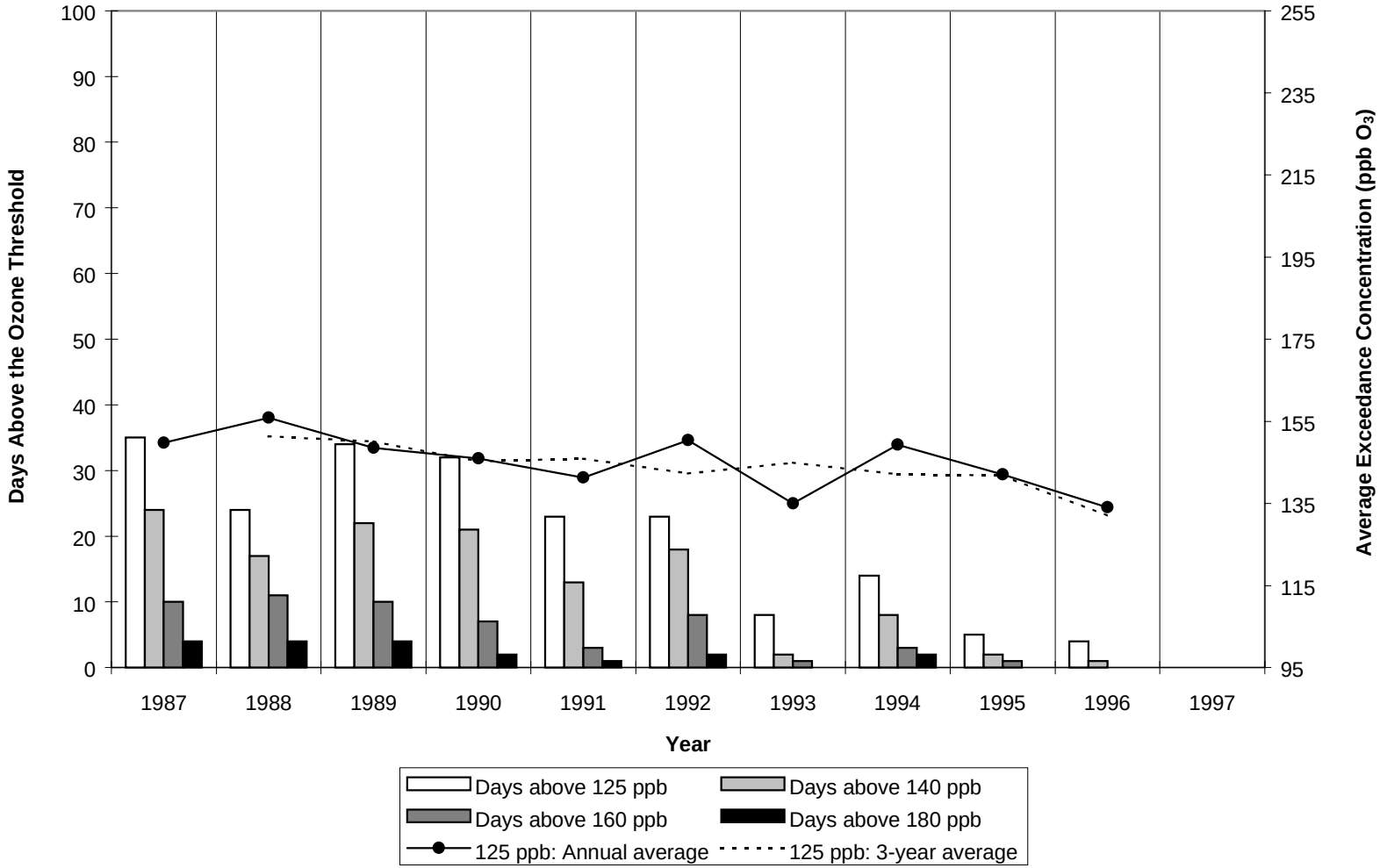

Figure 7-5. Total number of exceedances of the 1-hr Ozone NAAQS the Los Angeles North Main Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1997.

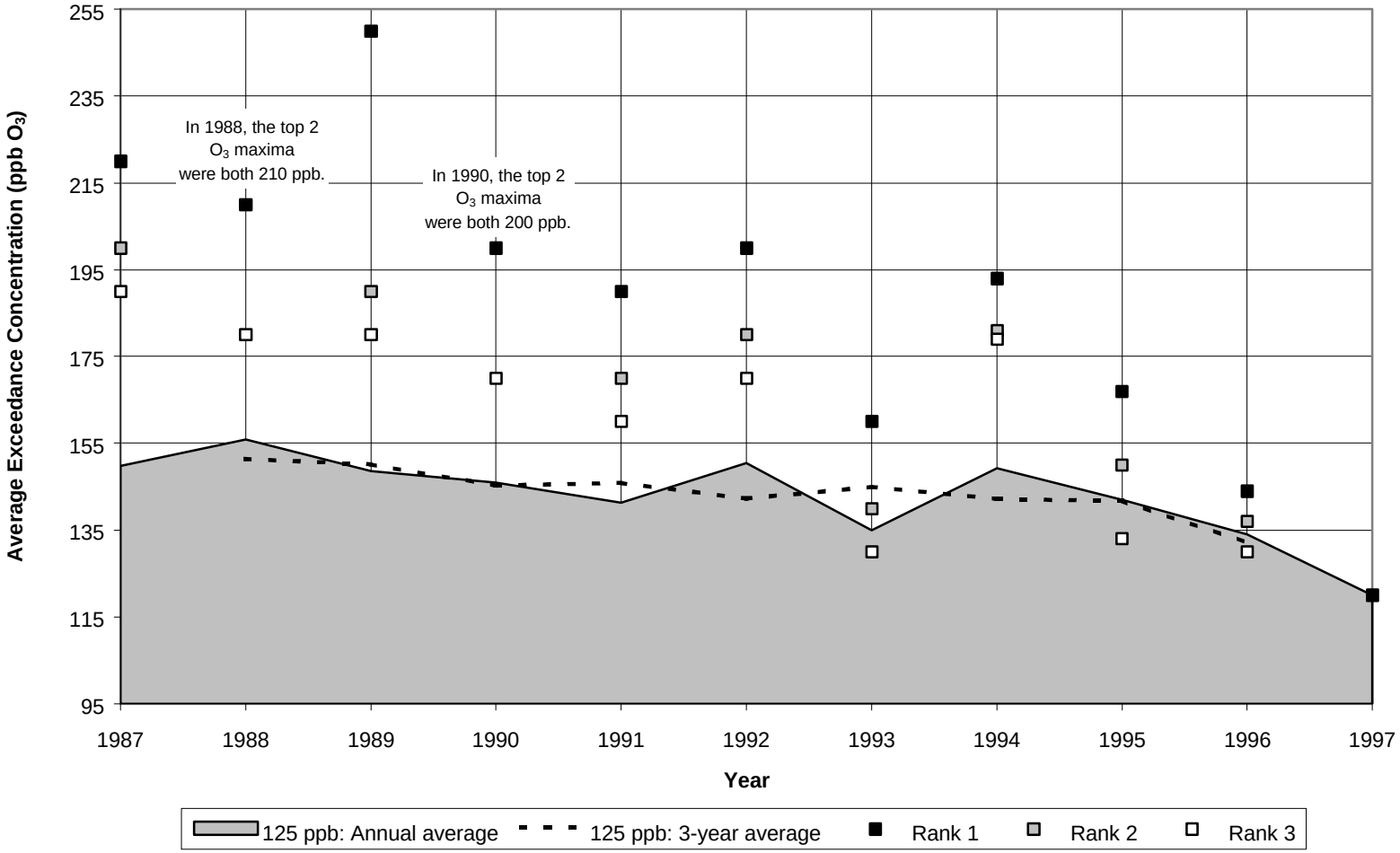

Figure 7-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS for the Los Angeles North Main Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1997.

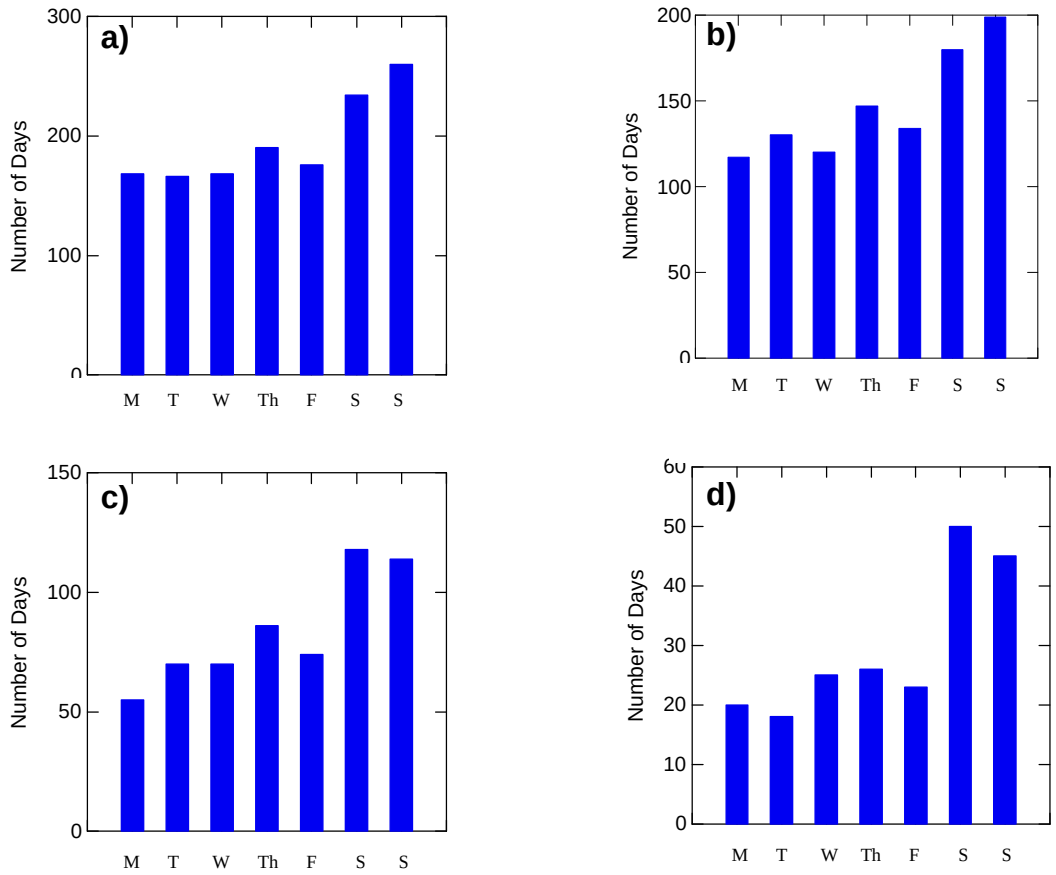

Figure 7-7. Number of days above a threshold ozone concentration by day of week for the Los Angeles North Main Street site from 1987 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

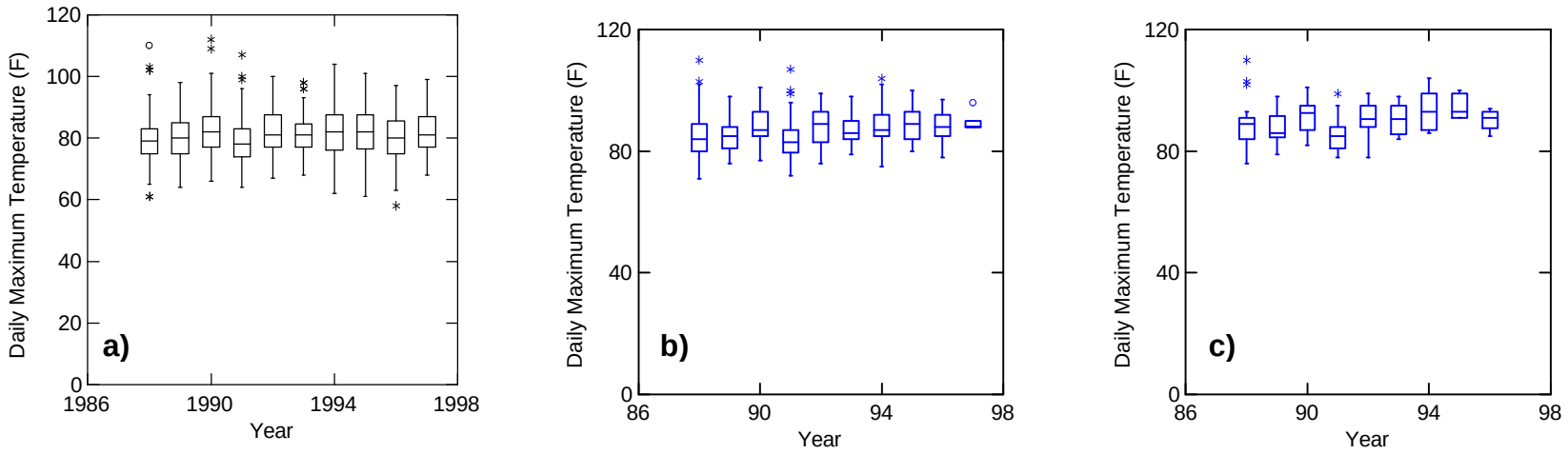

Figure 7-8. Daily maximum temperature at the Los Angeles North Main Street site: a) all daily maximum temperatures, b) daily maximum temperature on days when the daily maximum ozone concentrations were above the California Ozone Standard, and c) daily maximum temperature on days when the daily maximum ozone concentrations were above the 1-hr Ozone NAAQS. Temperature measurements from 1988 to 1995 were made at the NWS station at the Los Angeles International Airport.

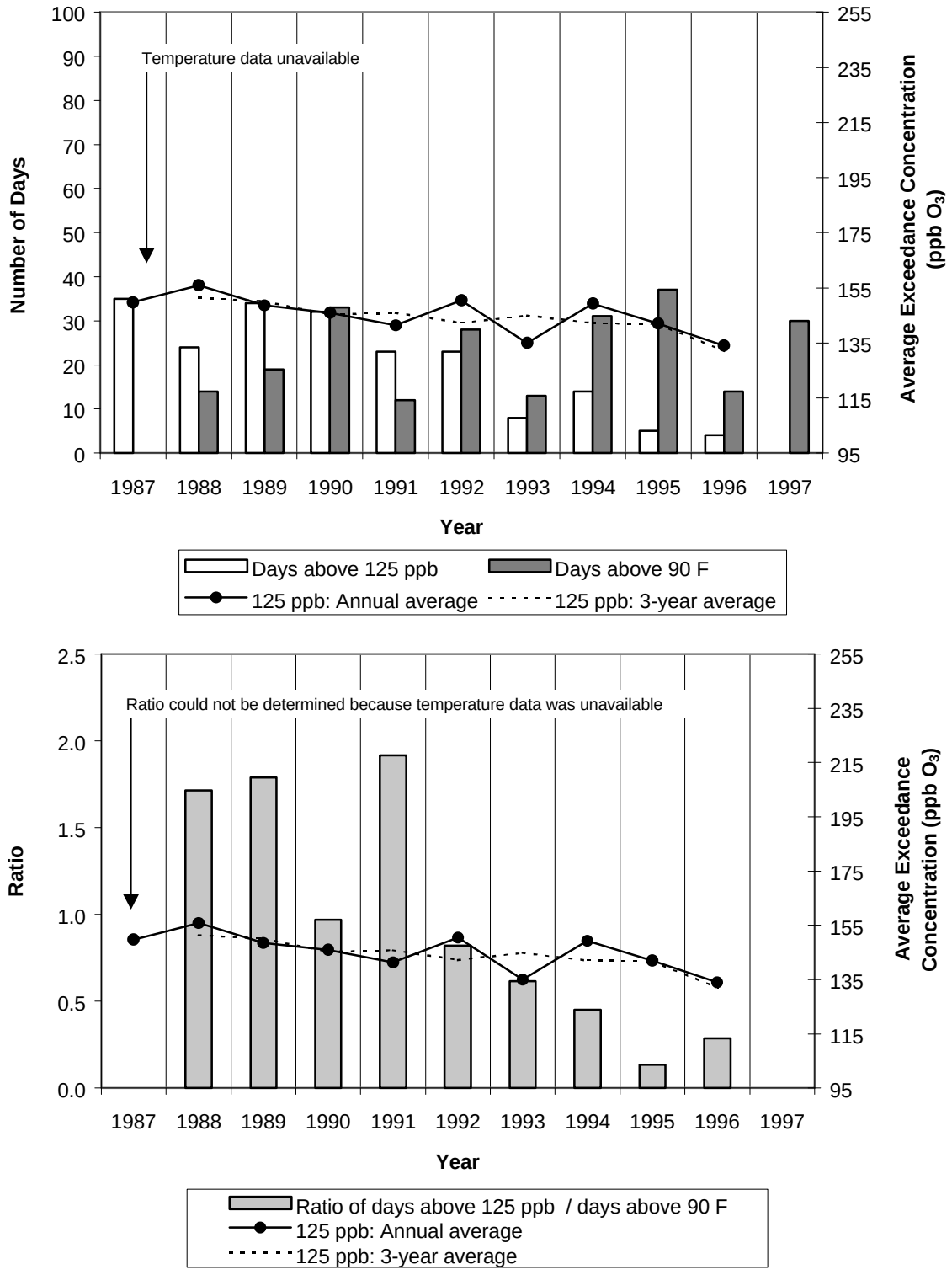

Figure 7-9. Number and ratio of the exceedances of the 1-hr Ozone NAAQS by meteorology for the Los Angeles North Main Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1997.

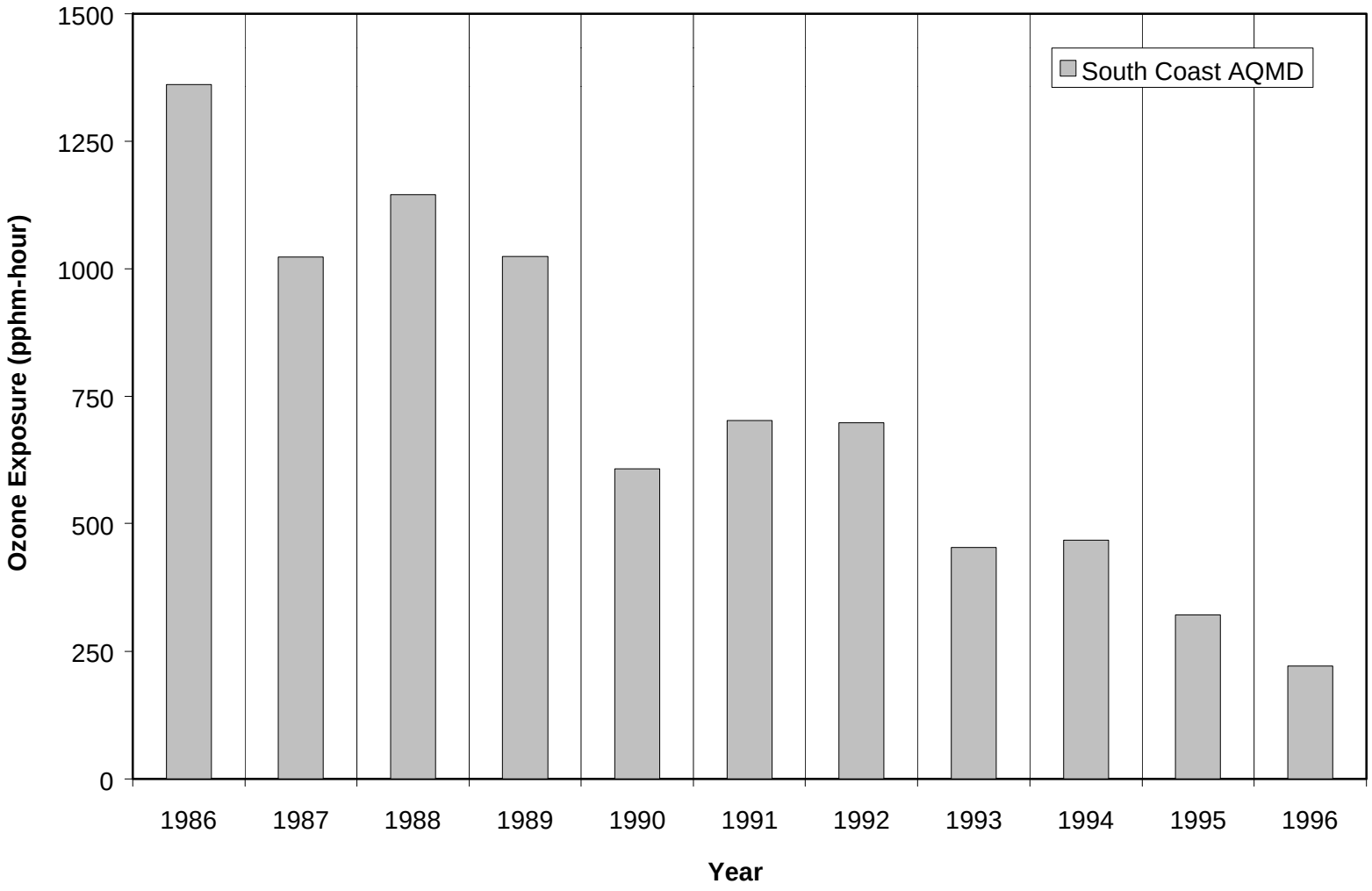

Figure 7-10. Cumulative population-weighted exposure hours of the broader South Coast air basin to exceedances of the California Ozone Standard.

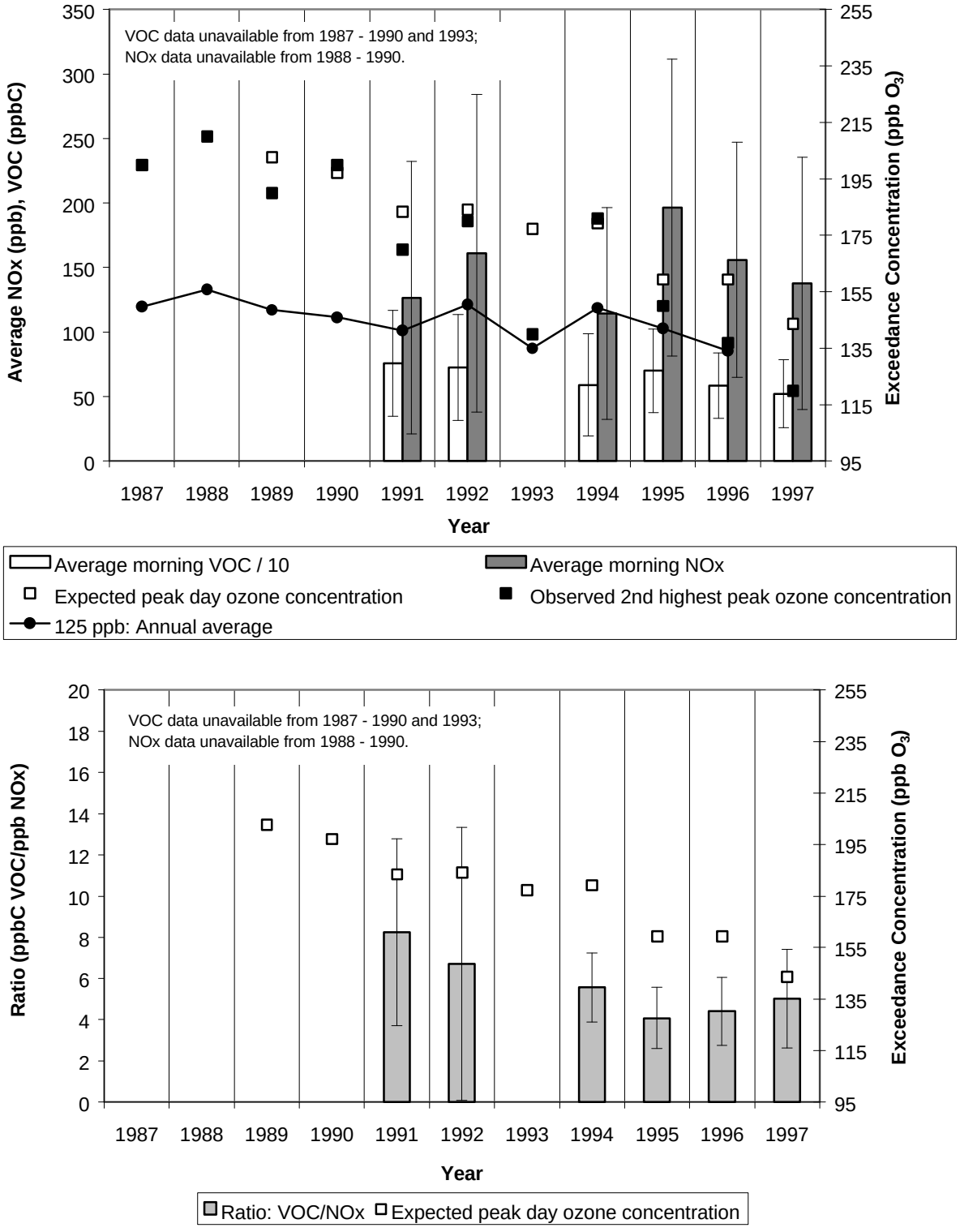

Figure 7-11. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the Los Angeles North Main Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1997.

Figure 7-12. Variability of the EPDC using native variability techniques for the Los Angeles North Main Street site.

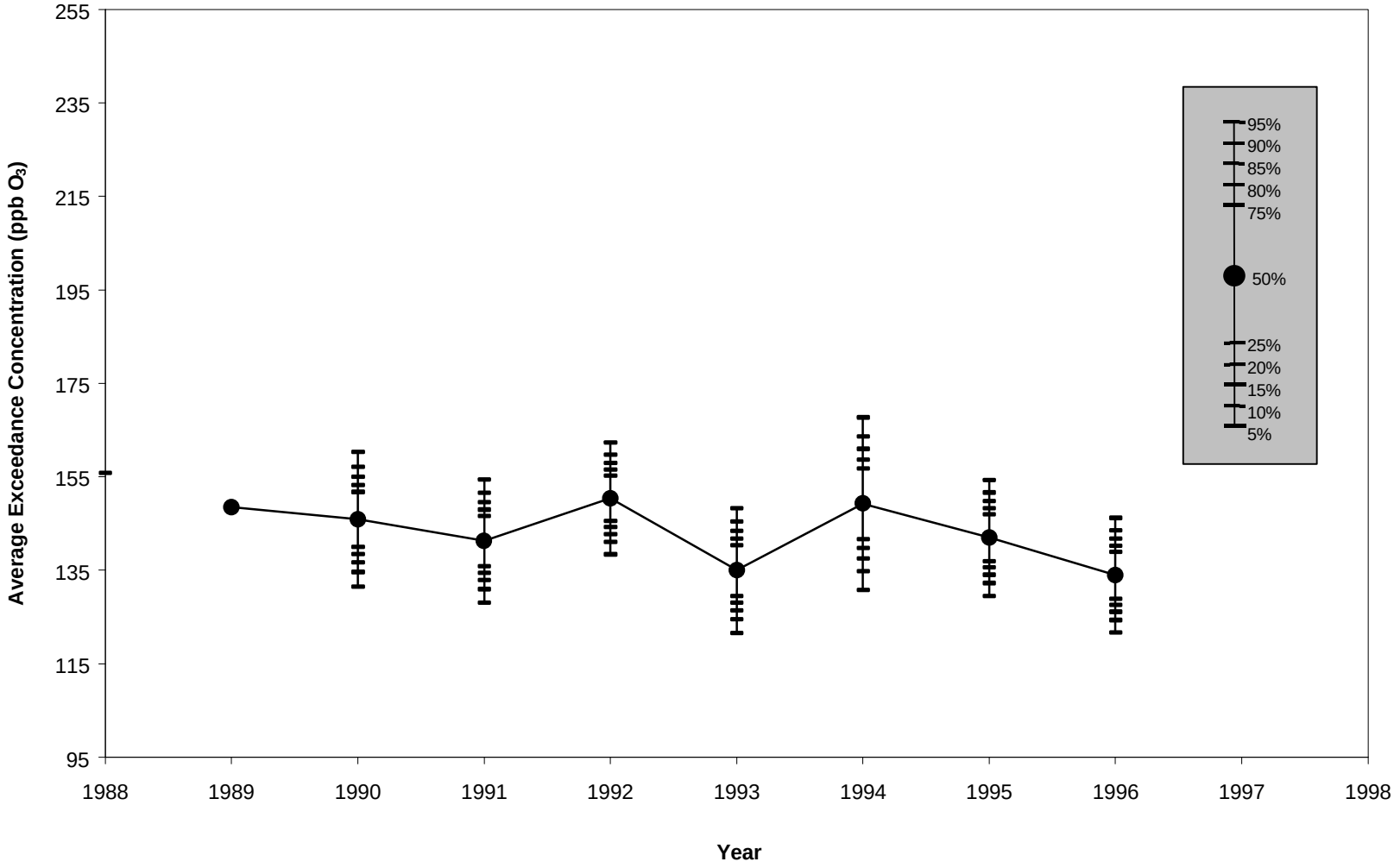

Figure 7-13. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the Los Angeles North Main Street site.

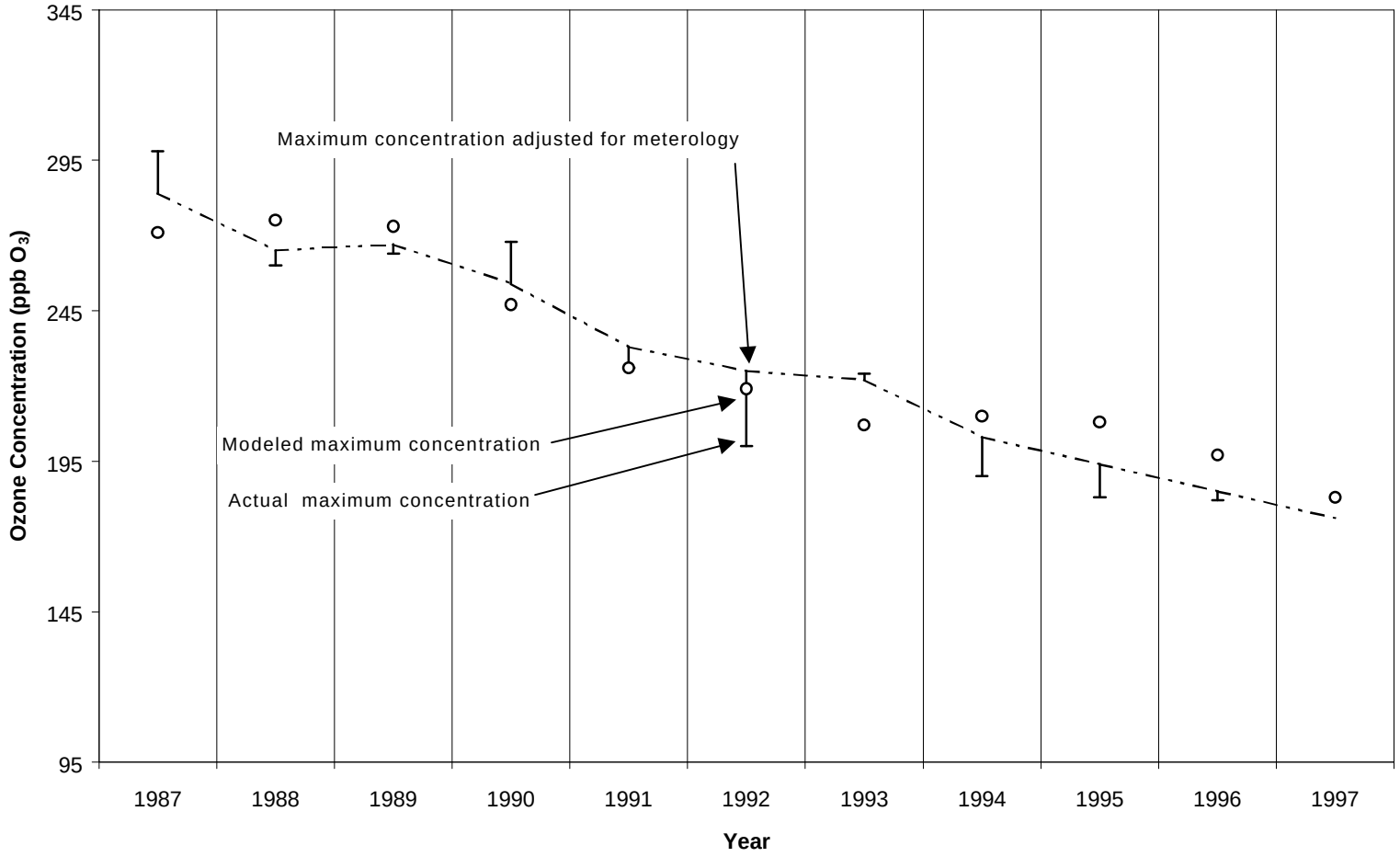

Figure 7-14. Meteorology adjustment of the maximum ozone concentrations using the Cox and Chu probability distribution technique for a site in the Los Angeles MSA.

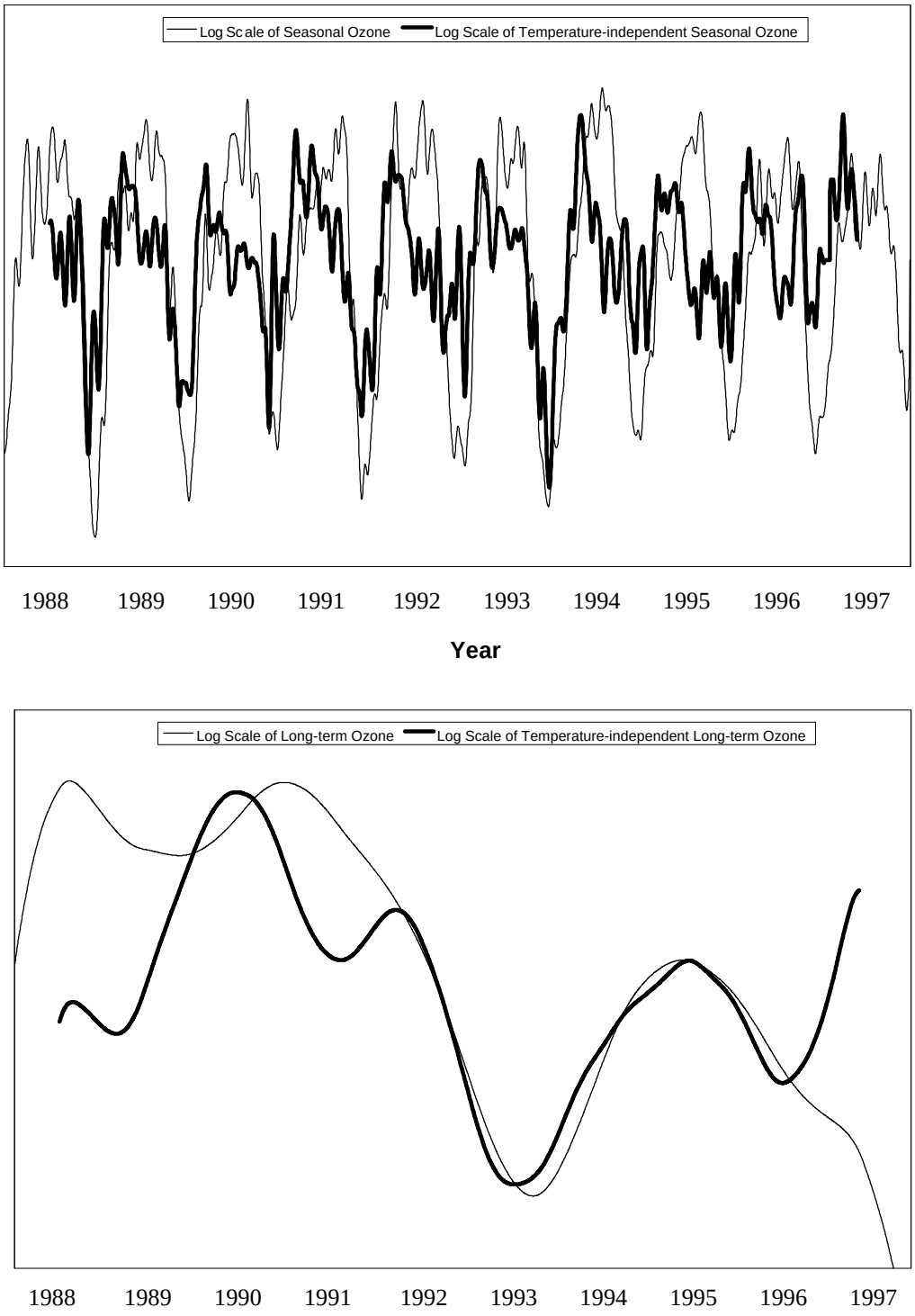

Figure 7-15. Meteorology adjustment of Los Angeles ozone concentrations using the Rao and Zurbenko filtering technique: a) seasonal component of ozone concentrations and b) long-term component of ozone concentrations (Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999).

Table 7-1. Summary of statistical and adjustment analyses performed on data from the Los Angeles North Main Street site.

Statistical Analyses	Trend in 1987-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward Inconclusive
Running 3-yr average of exceedance concentration	Downward
Total number of exceedances	Downward
Maximum concentrations	Downward
Number of exceedances by meteorology	Downward
Cumulative population-weighted exposure hours	Downward
Morning precursor concentrations	Inconclusive
Morning VOC/NO_x ratios	Downward
Adjustment Analyses	**Trend in 1987-1997 Ozone**
Expected peak day concentrations	Downward
Native variability of average daily maximum ozone concentrations	Downward
Native variability of average exceedance concentrations	Inconclusive
Meteorological adjustment using probability distribution (Cox and Chu)	Downward
Meteorological adjustment using filtering techniques (Rao and Zurbenko)	Inconclusive

8. SAN DIEGO TRENDS IN OZONE

8.1 OVERVIEW

The air quality at the PAMS Type 2-like ARB 12th Street site in San Diego was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1–hr Ozone NAAQS were considered in the analyses. **Figure 8-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for the site from 1989 to 1997. **Figure 8-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for the site from 1989 to 1997. These figures illustrate that there was a substantial decline in the number of exceedances per year from 1989 to 1997.

The San Diego 12th Street site is an ARB long-term trend site that has similar characteristics to a PAMS Type 2 site. This PAMS Type designation identifies the site as a maximum ozone precursor emission site. The analyses involving exceedances of the 1-hr Ozone NAAQS at the San Diego 12th Street site are given special focus in this section; the analyses involving the California Ozone Standard at the San Diego 12th Street site are presented in Appendix F.

The San Diego 12th Street site presents several possible issues that could affect trends:

- Reporting units changed from pphm to ppb on December 31, 1992.
- No temperature measurements were available at the San Diego 12th Street site.
- San Diego Airport NWS station temperature measurements were used to supplement the San Diego 12th Street site measurements from 1989 through 1995.
- Concurrent NO_x and hydrocarbon measurements were only available from 1993 through 1997.

Several statistical analyses of the ozone air quality at the site were performed, and the analysis uncertainties were used to interpret the trends. The ARB performed a statistical analysis of the total exposure hours for the San Diego Air Pollution Control District, and that analysis is also discussed in this section.

Adjustment techniques were applied to the San Diego 12th Street site to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was expected that the variability would add an additional uncertainty to the trend analyses. Adjustment techniques performed by other researchers for the San Diego 12th Street site (or a nearby site) are also discussed in order to investigate the uncertainty in the trends analysis as a function of those techniques. The findings of all the adjustment techniques are discussed in terms of the statistical analyses (Section 8.2) to establish a consensus among the different analysis approaches.

8.2 STATISTICAL ANALYSES

The statistical analyses of the air quality at the San Diego 12th Street site revealed a decline in the ozone concentrations from 1989 to 1997 as measured by the following indicators: the average exceedance concentration, the 3-yr running average exceedance concentration, the number of exceedance days, the highest daily maximum ozone concentration, and the cumulative exposure hours. Some statistics did not reveal clear trends and were also subject to large analysis uncertainties including the ratio of exceedance days to elevated temperature days and the ratio of early morning precursor concentrations.

8.2.1 Average exceedance concentration

Figure 8-3 shows the distribution of the daily maximum ozone concentrations at the San Diego 12th Street site from 1989 to 1997. Figure 8-3a shows that the majority of the daily ozone concentrations were below the California Ozone Standard threshold concentration. Figure 8-3 demonstrates that the interquartile range and median daily maximum ozone concentrations decreased from 1989 through 1992 and remained low through 1997. All three figures demonstrate that exceedances of either standard were less common past 1991. There were fewer outlier points and smaller ranges in the ozone concentrations after 1991, demonstrating that the highest concentrations were closer to the average daily maximum ozone concentrations in later years.

Figure 8-4 shows the average exceedance concentrations at the San Diego 12th Street site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in Figure 8-3 are still distinguishable when the analysis uncertainty of the exceedance concentrations is considered. However, only a single exceedance of the 1-hr Ozone NAAQS occurred after 1992. As a result, the average exceedance concentration in 1993, 1994, 1996, and 1997 is off-scale. This demonstrates the reduction of the average exceedance concentration after 1992. The same plot applied to the average California ozone exceedance concentrations and analysis uncertainties (Appendix F) shows that long-term trends in the average exceedance concentration that were suggested in Figure 8-3 are not distinguishable when the analysis uncertainty of the exceedance concentrations is considered.

8.2.2 Running 3-year average of exceedance concentration

The running 3-year average concentrations of the 1-hour Ozone NAAQS exceedances are presented in Figure 8-4. Because there were no exceedances of the 1-hr Ozone NAAQS in 1993, 1994, 1996, and 1997, the 3-yr running average of the average exceedance concentrations for 1992 through 1997 were determined using the single highest non-exceedance concentration in the years with no actual exceedances. The figure illustrates that the average exceedance concentrations gradually decline over the entire time period when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period.

8.2.3 Total number of exceedances of the standard

Figure 8-5 demonstrates that the number of exceedance days decreased from 1989 to 1997. The numbers of exceedances associated with both high (above 160 ppb) and low (above 125 ppb) daily maximum ozone concentrations dramatically decreased from 1989 to 1991 and remained low through to 1997. Exceedance concentrations above 125 ppb were uncommon after 1991.

8.2.4 Identification of the highest exceedance concentrations

Figure 8-6 shows the top three exceedance concentrations experienced at the San Diego 12th Street site. This figure illustrates that the highest daily maximum ozone concentrations decreased in magnitude from 1989 to 1997. The highest exceedance concentrations were much greater than the average exceedance concentrations during years with more exceedances and higher average exceedance concentrations (e.g., 1989 to 1991). However, the third highest exceedance concentrations were close to the average exceedance concentrations. This suggests that the years with fewer exceedances and lower exceedance concentrations are more representative of typical (i.e., average) air quality at the San Diego 12th Street site.

8.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated (**Figure 8-7**), no trend was discernible for the 1-hr Ozone NAAQS. However, few exceedances of this standard occurred after 1991. When lower ozone concentration thresholds were considered, a larger number of days above the ozone concentration thresholds were observed on Saturday and Sunday. This suggests that, statistically, there is a greater chance for higher ozone concentrations on Saturday and Sunday. This trend was also observed in Los Angeles.

8.2.6 Number of exceedances of the standard by meteorology

Temperature measurements were not made at the San Diego 12th Street site. In order to perform analyses of the ozone concentrations in the context of meteorological parameters, temperature measurements made at the San Diego Airport NWS station from 1989 to 1995 were used. However, there were no temperature measurements made at the San Diego 12th Street site to correlate to the San Diego Airport NWS station temperature measurements. Correlation was demonstrated between the San Diego Airport NWS station temperature measurements and a site in proximity to the San Diego 12th Street site. The correlation plot is presented in Appendix A. The subsequent analyses involving temperature measurements use the San Diego Airport temperature measurements, but the finding of these analyses should be regarded with caution.

Figure 8-8 presents the distribution of the daily maximum temperatures from 1989 to 1997. The figure shows that the bulk of the daily maximum temperatures (i.e., interquartile

range) were not statistically different on the exceedance days than during all of the summertime days. The interquartile range of the daily maximum temperatures falls below 90°F. Slightly higher temperatures were observed in 1992 on the exceedance day. This suggests that the meteorology (with temperature as an indicator of meteorology in general) was not atypical of the average summertime meteorology at the San Diego 12th Street site on 1-hr Ozone NAAQS days.

Figure 8-9 shows a bar graph of the number of days above the ozone standard and the number of days above 90°F for 1989 to 1997 and a bar graph of the ratio of the number of days above the ozone standard and the number of days above 90°F. The plots also show the annual average exceedance concentrations and 3-yr running averages of the exceedance concentrations. These plots demonstrate that the ratio of the number of days above the 1-hr Ozone NAAQS and the number of days above a maximum daily temperature of 90°F has decreased from 1989 to 1995. However, this analysis was limited by the following observations: there were no exceedances of the 1-hr Ozone NAAQS in 1993, 1994, 1996, or 1997; there were no days above 90°F in 1993 or 1995; and temperature measurements were not available in 1996 and 1997. Given the lack of data, this analysis was inconclusive.

8.2.7 Cumulative population-weighted exposure hours

Figure 8-10 shows an estimate of the cumulative population-weighted number of hours that the San Diego Air Pollution Control District (SDAPCD) is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1997. This statistic consolidates into a single indicator the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances.

This broader perspective on air quality confirms previous findings that ozone exposure in the broader San Diego area has dramatically decreased since 1989. Figure 8-10 also demonstrates that the exposure hours decreased in the early to mid 1990s and remained low through 1996. This indicates that the low ozone concentrations and number of exceedances at the San Diego 12th Street site after 1992, observed in earlier figures, were typical of ozone concentrations in the entire SDAPCD. The analysis suggests that when a broader area is considered, the air quality in the San Diego area has improved from the late 1980s to the late 1990s. However, the reductions in ozone exposure hours for the entire SDAPCD appear to lag behind the reductions in ozone concentrations and number of exceedances at the San Diego 12th Street site by two years. Finally, a statistical evaluation of the exposure-hours was not available to assess the errors on the analysis.

8.2.8 Exceedance concentrations as a function of early morning precursor concentrations

Figure 8-11 illustrates that the exceedance concentrations are not clearly related to the average early morning NO_x and VOC precursor concentrations. The average exceedance concentrations decreased from 1992 to 1997 (see Section 8.2.1) although the daily maximum

ozone concentration in 1995 was atypically high. The second highest daily maximum ozone concentrations also decreased over the same time period. The average precursor concentrations and the ratio of average early morning NO_x and VOC measurements did not appear to change dramatically over the time period. The average ratios appear to be in the VOC-limited regime, suggesting that reductions in VOC concentrations could result in lower maximum ozone concentrations. The lower ozone concentrations and number of exceedances of the 1-hr Ozone NAAQS from 1992 to 1997 are difficult to correlate to precursor emissions concentrations.

8.3 ADJUSTMENT ANALYSES

Statistical analyses applied to the San Diego 12th Street site did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques applied to the San Diego 12th Street ozone measurements and discussed in this section were used to assess whether the uncertainty analysis is, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques were used to estimate the uncertainty in the ozone measurements due to atmospheric or meteorological variability from 1989 to 1997 and differences in meteorology from year to year. It is anticipated that the adjustment techniques will allow for more clear trends to be determined.

8.3.1 EPDCs as a function of early morning precursor concentrations

Figure 8-11 does not conclusively show that the EPDCs are related to the ratio of the average early morning NO_x and VOC precursor concentrations. The EPDC values dropped dramatically from 1991 to 1994 and remained low from 1995 to 1997. In contrast, the precursor concentrations remained constant from 1993 to 1997. The lack of precursor concentrations prior to 1993 limits the conclusions that can be drawn in this analysis. This is consistent with the analysis performed in Section 7.2.8 which suggested that reductions in the average and second highest peak ozone concentrations in the mid to late 1990s were not conclusively related to changes in the ratio of the average early morning precursor concentrations.

8.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis due to atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this report, the concept of native variability was also applied to average daily maximum ozone concentrations. This allows a direct comparison between the uncertainties due to the analysis and the uncertainties due to atmospheric and meteorological variability.

Figure 8-12 demonstrates the native variability about the EPDC. When 95 percent confidence limits are associated with the native variability estimates, significant reductions in ozone concentrations are seen from 1991 to 1997 (with the greatest reductions in ozone concentration occurring between 1993 and 1994 to 1997). This is consistent with the cumulative population-weighted exposure hour statistical analysis that suggested that ozone concentrations decreased from the late 1980s to the late 1990s. Notably, the native variability estimates on the EPDC suggest that dramatic changes in ozone concentrations did not occur until 1994. This is consistent with the cumulative exposure-hours analysis but contrary to all prior statistical analyses that identified the decreasing ozone concentrations that occurred two years earlier. However, this analysis does support the finding that the reduction in ozone concentrations from the late 1980s to the late 1990s is statistically viable. It is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This analysis also applies native variability principles to EPDCs and is therefore also biased against anomalous events on both sides of the spectrum.

Figure 8-13 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS. The lack of exceedances after 1992 limits the conclusions that can be drawn using this analysis technique. Notably, native variability limits on the average exceedance concentrations are similar to the analysis uncertainties that were considered in Section 8.2.1. However, native variability estimates suggest that the ozone concentrations in 1994 were not statistically different than ozone concentrations in 1991. This finding was not observed in any of the prior analyses.

8.3.3 Meteorology adjustment using the Cox and Chu probability distribution technique

Figure 8-14 shows the maximum daily ozone concentrations that have been adjusted to account for meteorology with a confidence limit of 95 percent by Cox and Chu (1998). This figure suggests a decreasing trend in ozone concentrations that is consistent with the EPDC estimates. This analysis was performed for a site that was in the San Diego MSA although the specific site location is unknown. Because the ozone concentrations at the site of focus to the Cox and Chu analysis were lower than those observed at the San Diego 12th Street site and because the decrease in ozone concentration in 1992 was not observed at either site, these findings should not be used to determine absolute concentrations for the adjusted ozone concentrations.

Figure 8-14 shows the actual maximum ozone concentrations, the modeled maximum ozone concentrations, and the adjusted maximum ozone concentrations. The modeled concentrations indicate how well the Weibull distribution fit the daily maximum ozone concentrations. The model did not capture the observed daily maximum ozone concentrations well in 1992 and 1995. The adjusted concentrations are adjusted from the modeled concentrations. They represent the modeled concentration that would be likely if the temperature, wind speed, and wind direction conditions within a particular year were identical to the average meteorological conditions.

When the daily maximum ozone concentrations are adjusted for meteorology, the trend in ozone concentrations appears to gradually decrease. High ozone concentrations are lowered (e.g., 1992), and low ozone concentrations are raised (e.g., 1995) using this smoothing technique. These findings make sense as meteorology can have both positive and negative effects on ozone formation. Finally, it is expected that the Cox and Chu method will bias against both high and low ozone concentrations that do not fit well to the probability distribution. This is demonstrated in 1992 and 1995 when the modeled ozone concentrations were substantially different than the actual (i.e., observed) ozone concentrations.

8.3.4 Meteorology adjustment using the Rao and Zurbenko filtering technique

At our request, the Kolmorov-Zurbenko filtering technique was applied to the San Diego 12th Street daily maximum ozone concentrations by a coworker of Dr. Rao, Steven Porter. **Figure 8-15** shows Mr. Porter's results for the maximum daily ozone concentrations that have been separated into two time scales of ozone variability and adjusted to filter out the effects of temperature (personal communication with Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999). Surface temperature was the sole surrogate for meteorology in this analysis. The adjusted ozone concentrations reveal a variable trend that is due to other long-term meteorological parameters (besides temperature) or policy and economic changes that have caused emissions changes to the MSA.

Figure 8-15a illustrates that seasonal variability in temperature did not have a dramatic impact on the observed ozone concentrations (i.e., only 26 percent of the ozone concentrations are explained by the normal seasonal variations in meteorology). Therefore, 74 percent of the seasonal ozone concentrations is not explained by temperature. This finding is consistent with the meteorology analysis performed in Section 8.2.6. This indicates that other meteorological parameters not used in this analysis are critical to ozone formation in the San Diego MSA. Some other possible parameters are latitude, longitude, elevation, station pressure, aerosol optical depth coefficients, terrain factors, monthly vertical ozone column depth, monthly albedo factor, total cloud cover, total opaque cloud cover, and precipitable water vapor.

Figure 8-15b illustrates that the long-term reduction in ozone concentrations was unaffected by temperature from 1989 to 1997. A clearly downward trend in the long-term daily maximum ozone concentrations is discernible using this technique as it was using other techniques (e.g., Cox and Chu, EPDC, average exceedance concentration, number of exceedance days). However, we know from the seasonal analysis that other meteorological parameters not used in this analysis are critical to ozone formation in the San Diego MSA. Therefore, decreasing ozone concentrations are the result of variations in some other atmospheric event on this time scale, such as variability in a different meteorological parameter, emissions, or economic factors. However, it is unclear how to interpret either of the findings in the context of analysis uncertainty.

8.4 SUMMARY OF SAN DIEGO AIR QUALITY TRENDS

Table 8-1 summarizes the findings from statistical and adjustment analyses performed on data from the San Diego 12th Street site. The consensus is that ozone concentrations have declined significantly between 1989 and 1997 at this site. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability and meteorology was found to obscure trends.

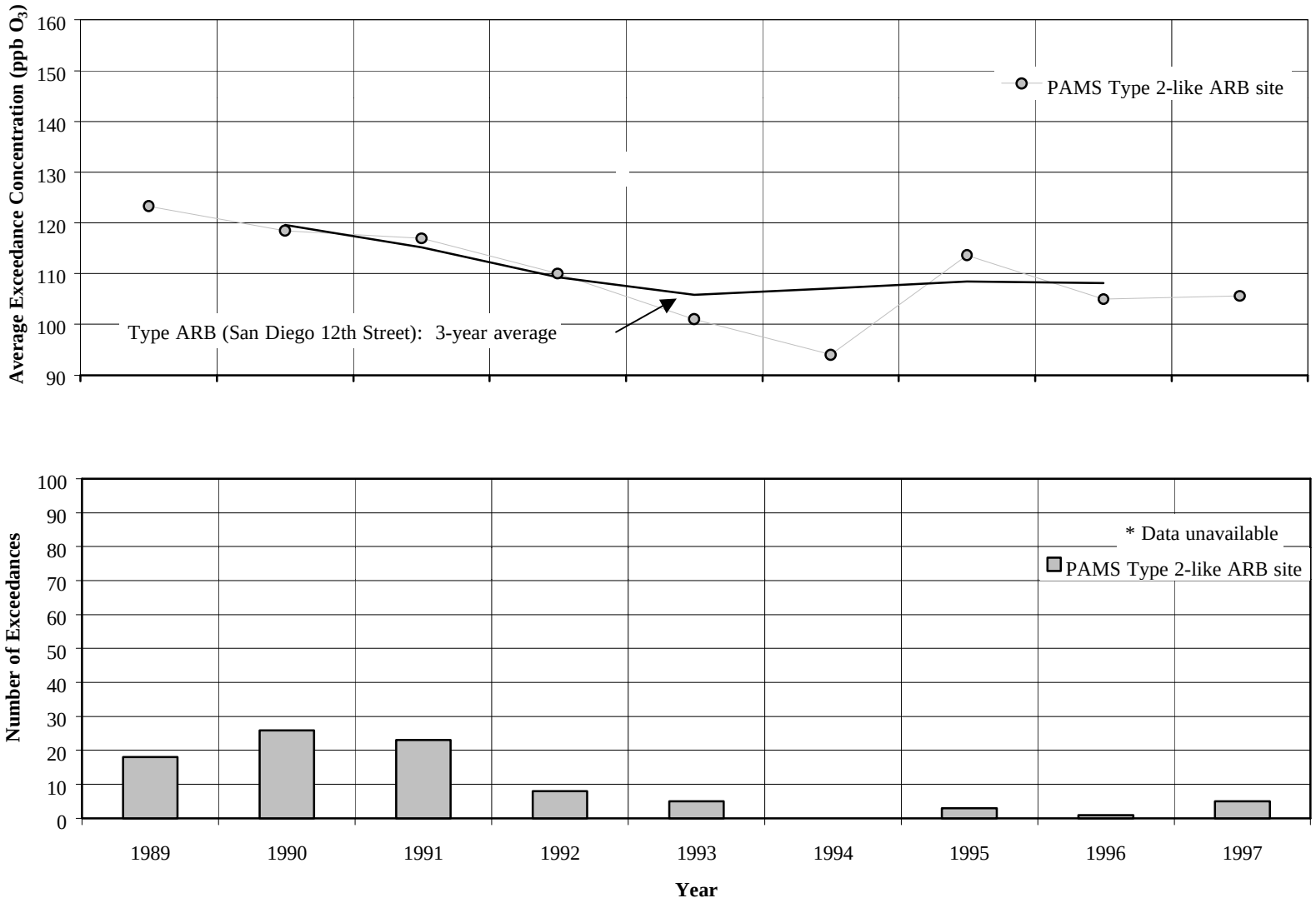

Figure 8-1. Exceedances of the California Ozone Standard at selected sites in the San Diego MSA. Averages were determined using the highest non-exceedance concentrations in 1994.

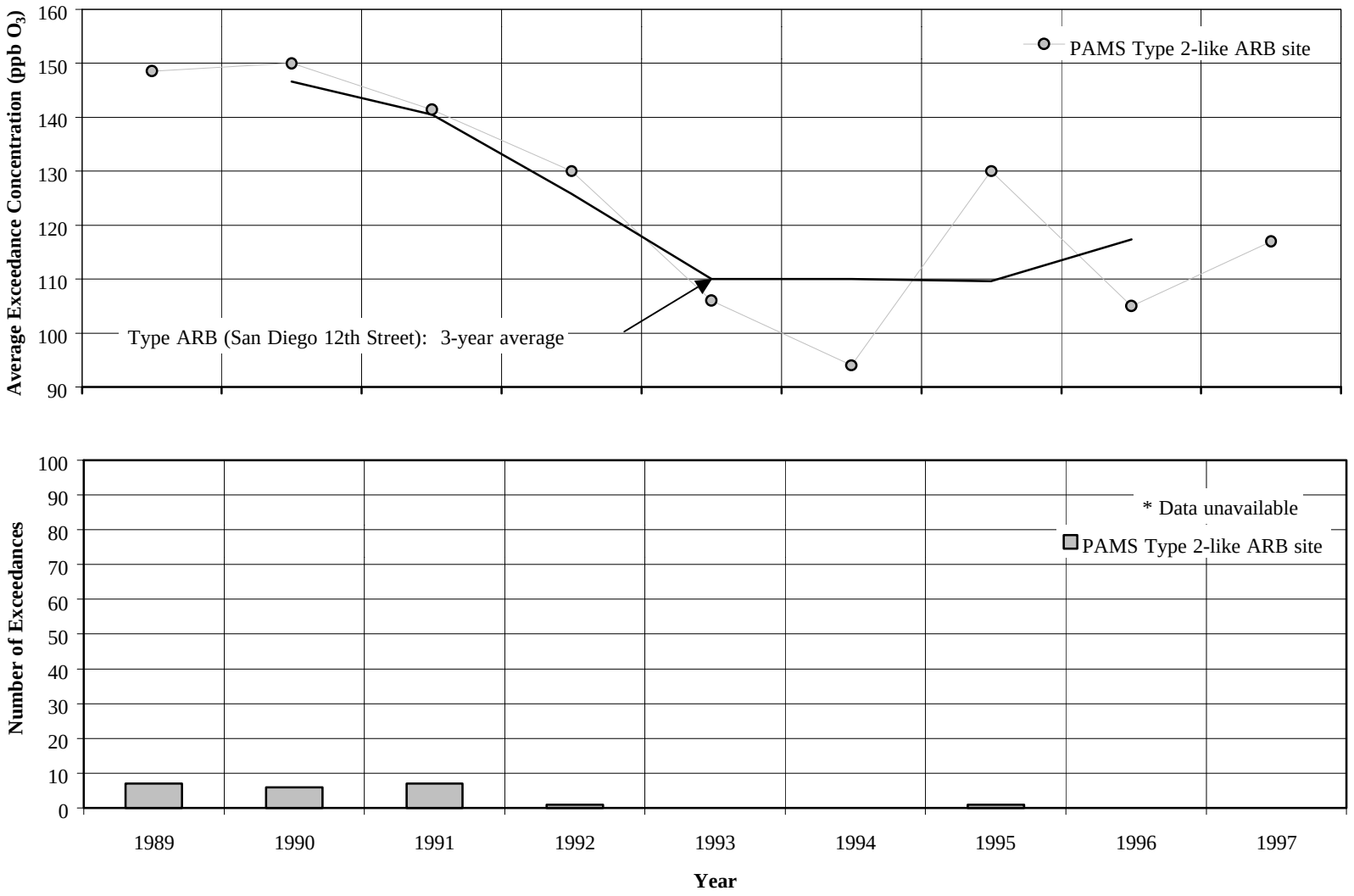

Figure 8-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the San Diego MSA. Averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997 (years in which the 1-hr Ozone NAAQS threshold concentration was not reached).

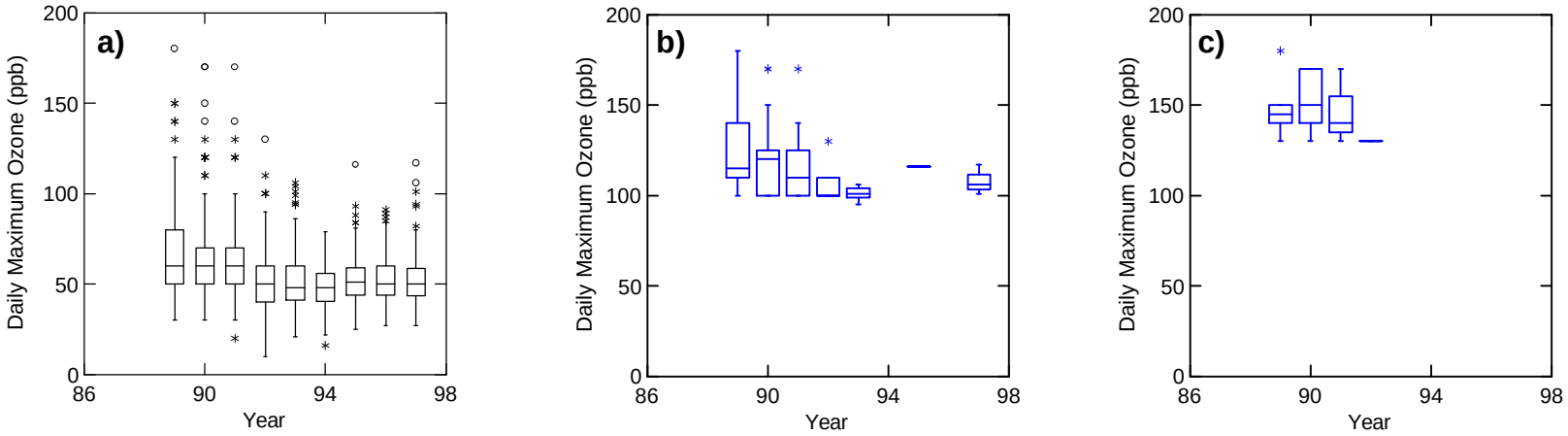

Figure 8-3. Daily maximum ozone concentrations for the San Diego 12th Street site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

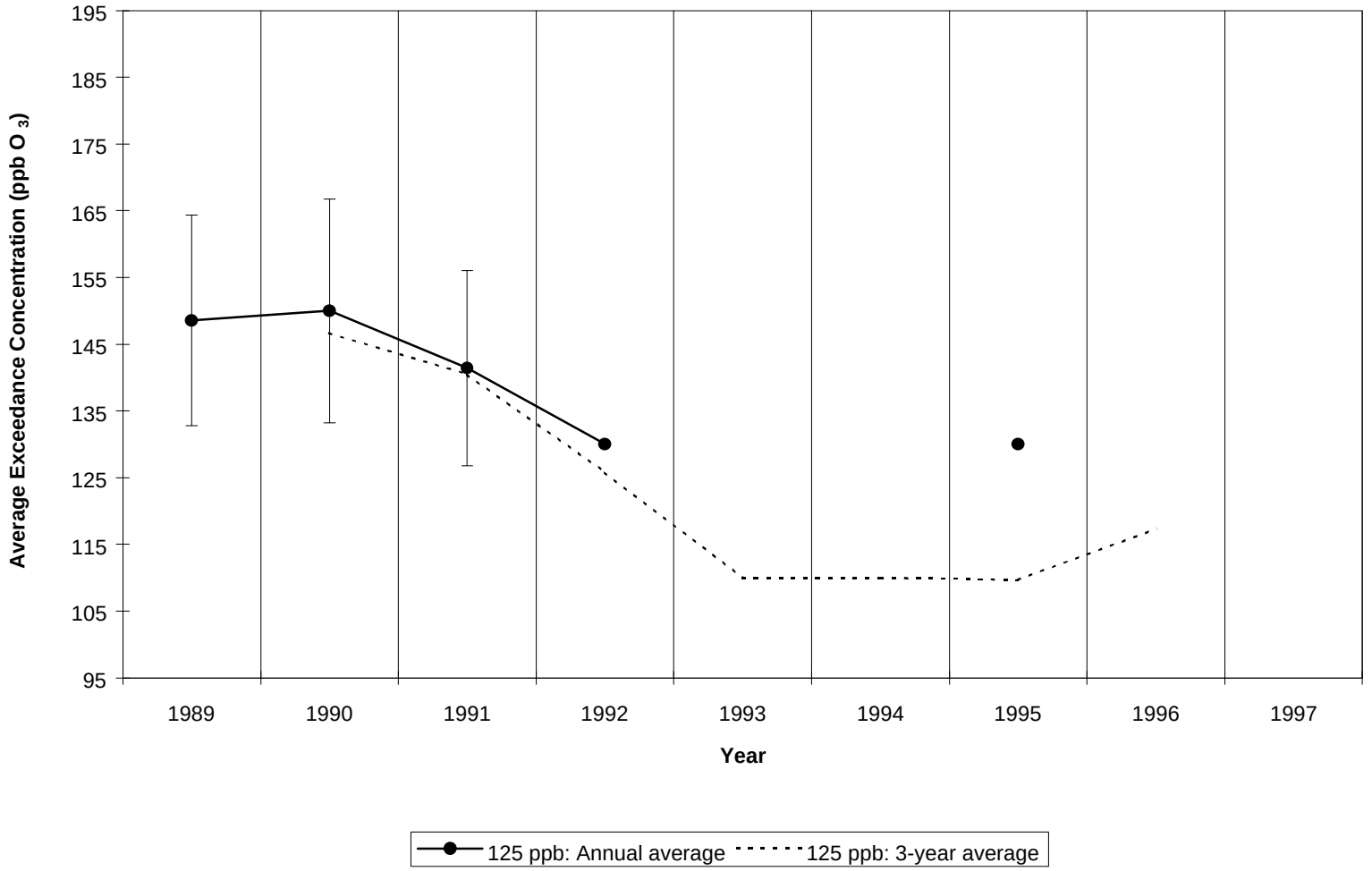

Figure 8-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty for the San Diego 12th Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997. Error bars indicate the analysis uncertainty on the average ozone concentrations.

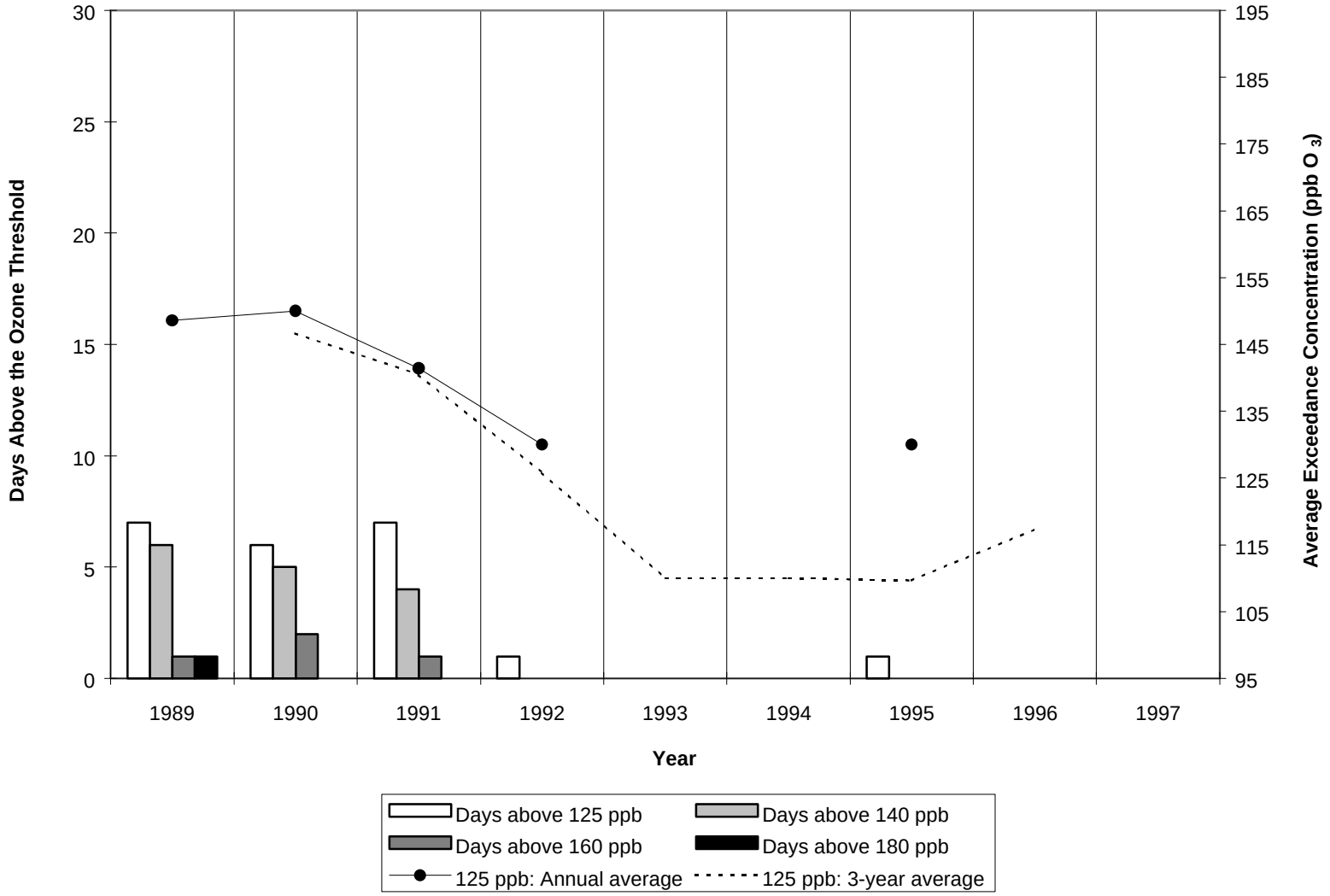

Figure 8-5. Total number of exceedances of the 1-hr Ozone NAAQS the San Diego 12th Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997.

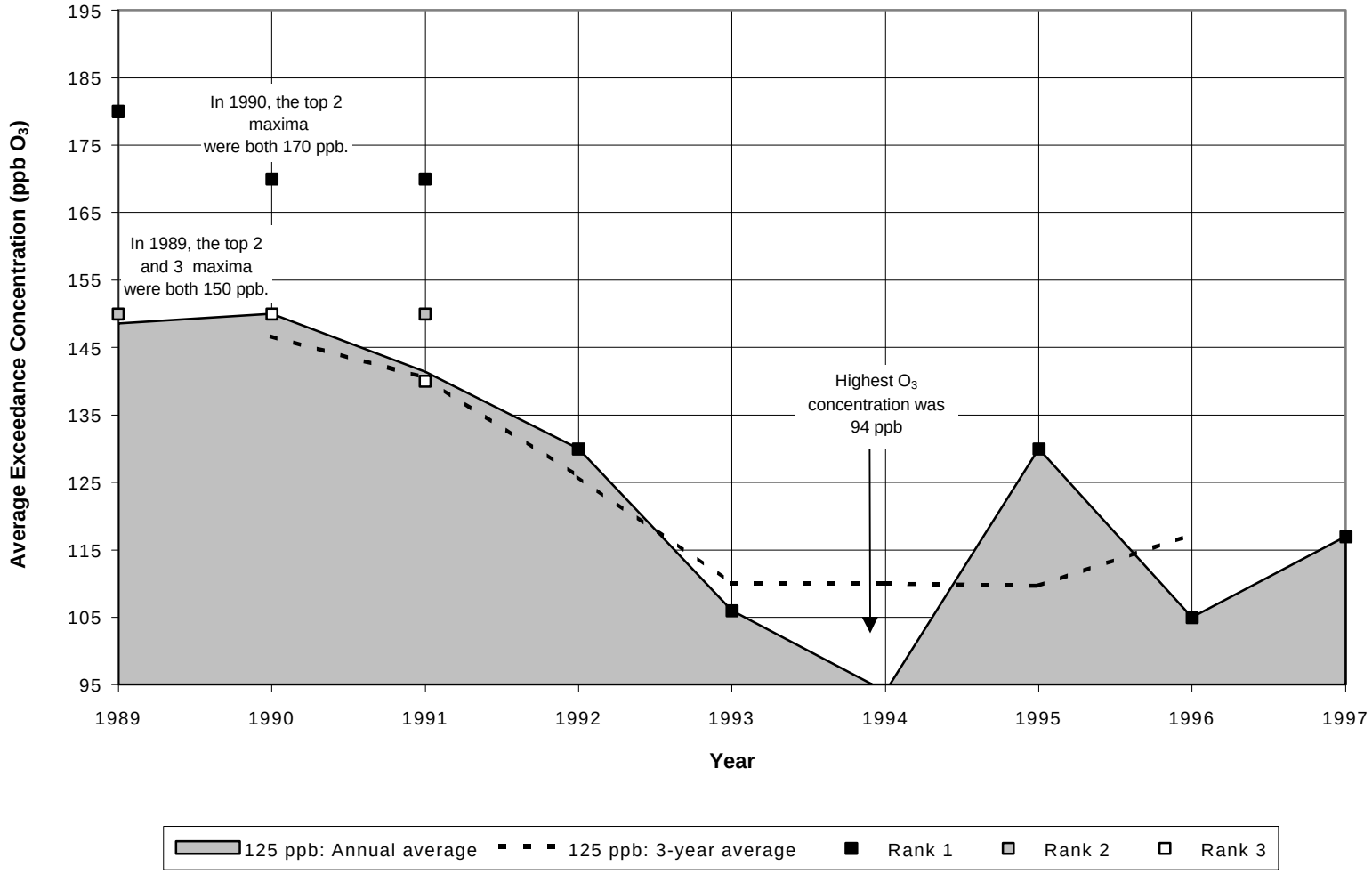

Figure 8-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS for the San Diego 12th Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997.

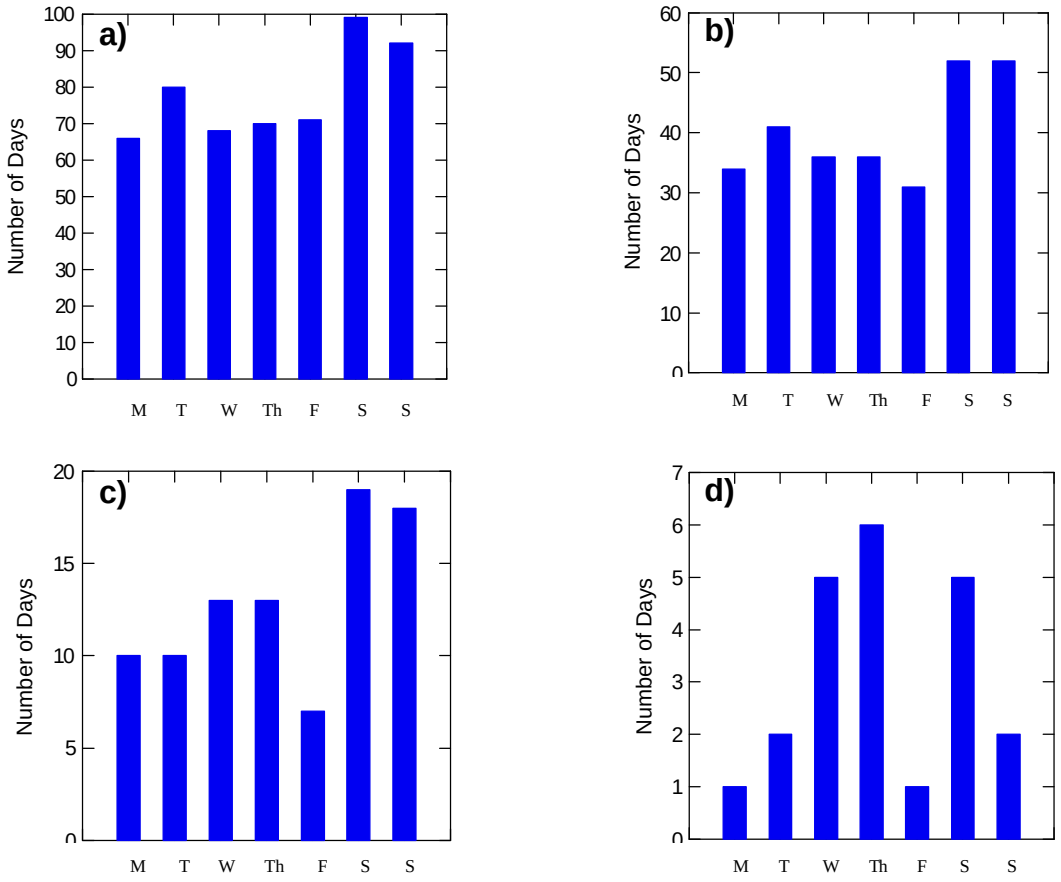

Figure 8-7. Number of days above a threshold ozone concentration by day of week for the San Diego 12th Street site from 1989 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

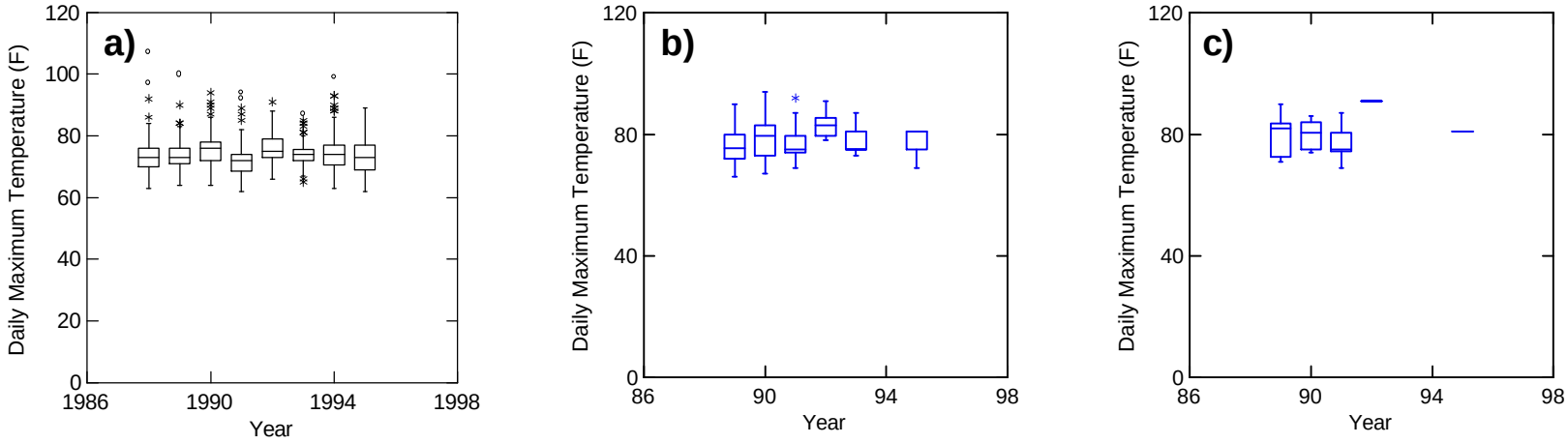

Figure 8-8. Daily maximum temperature for the San Diego 12th Street site: a) all daily maximum temperatures, b) daily maximum temperature on days when the daily maximum ozone concentrations were above the California Ozone Standard, and c) daily maximum temperature on days when the daily maximum ozone concentrations were above the 1-hr Ozone NAAQS.

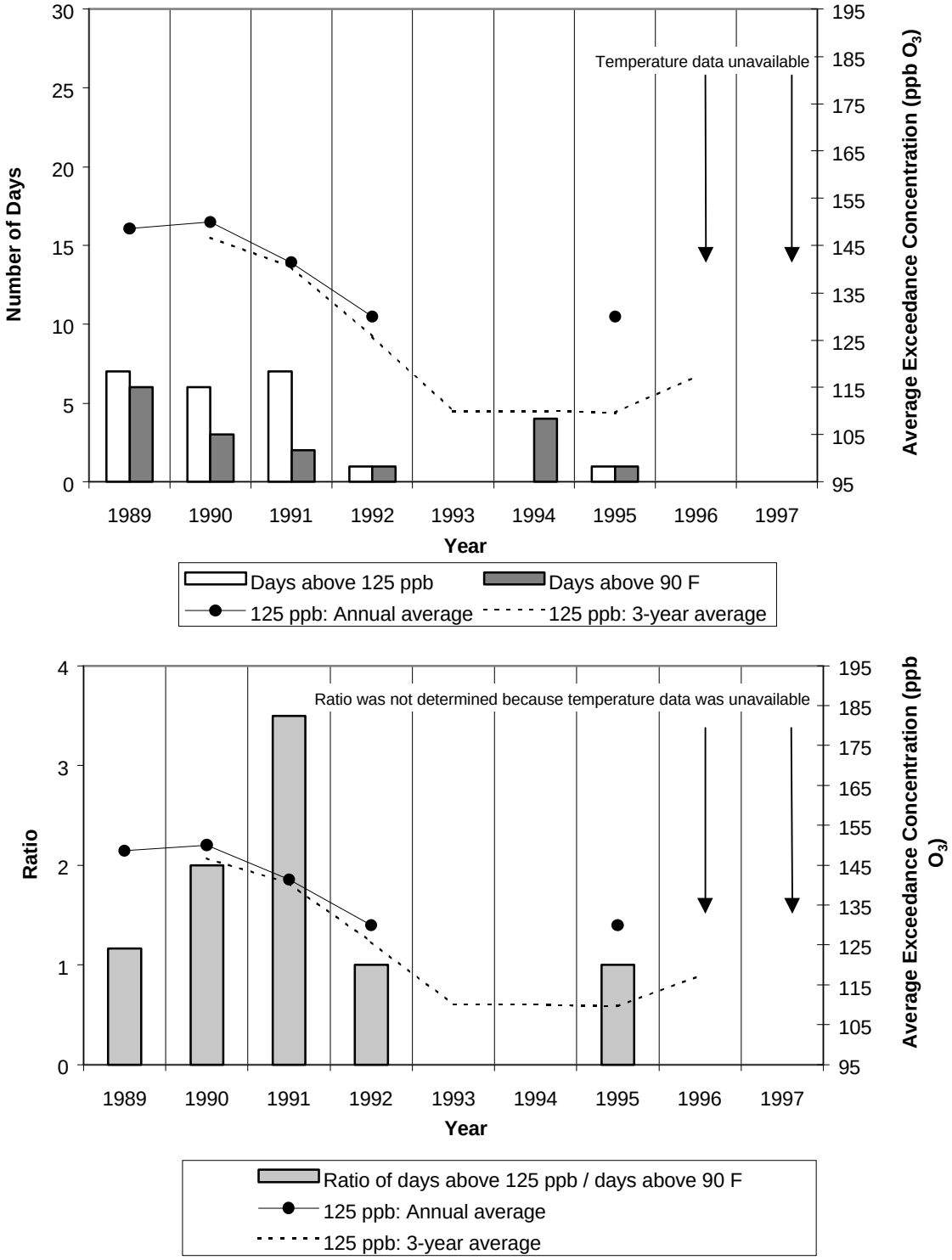

Figure 8-9. Number and ratio of the exceedances of the 1-hr Ozone NAAQS by meteorology for the San Diego 12th Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997.

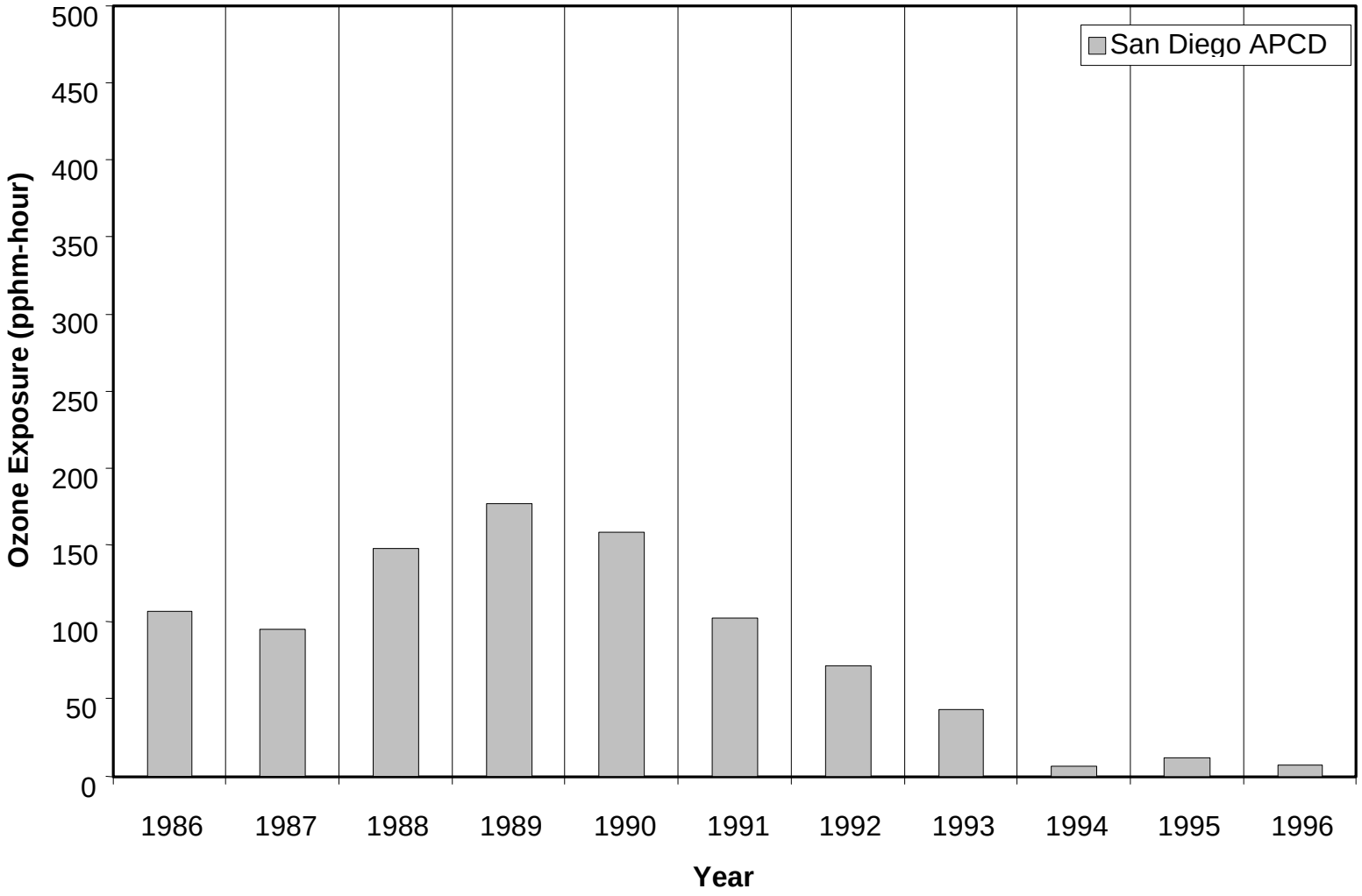

Figure 8-10. Cumulative population-weighted exposure hours of the broader SDAPCD to exceedances of the California Ozone Standard.

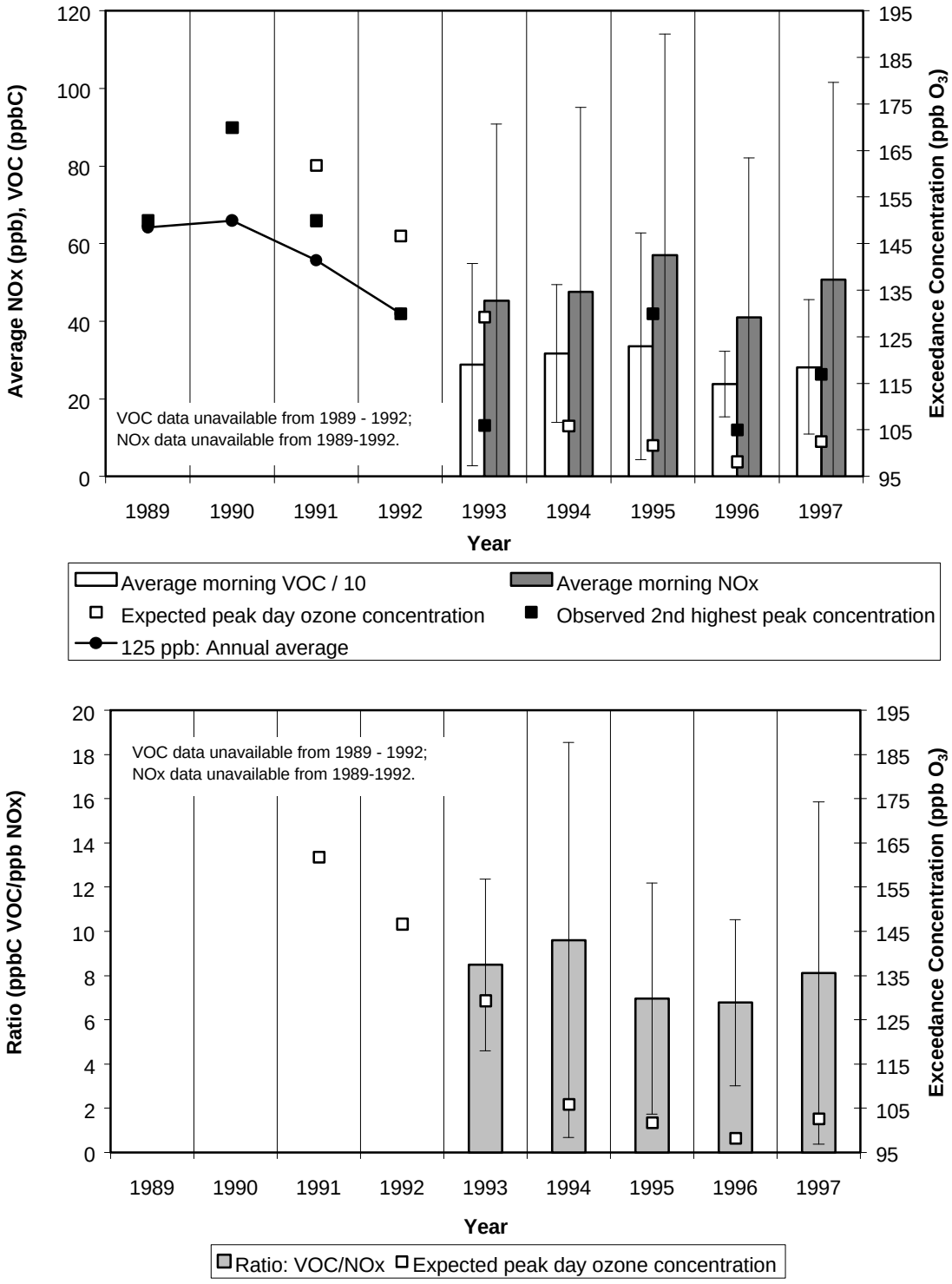

Figure 8-11. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the San Diego 12th Street site. Three-year averages were determined using the highest non-exceedance concentrations in 1993, 1994, 1996, and 1997.

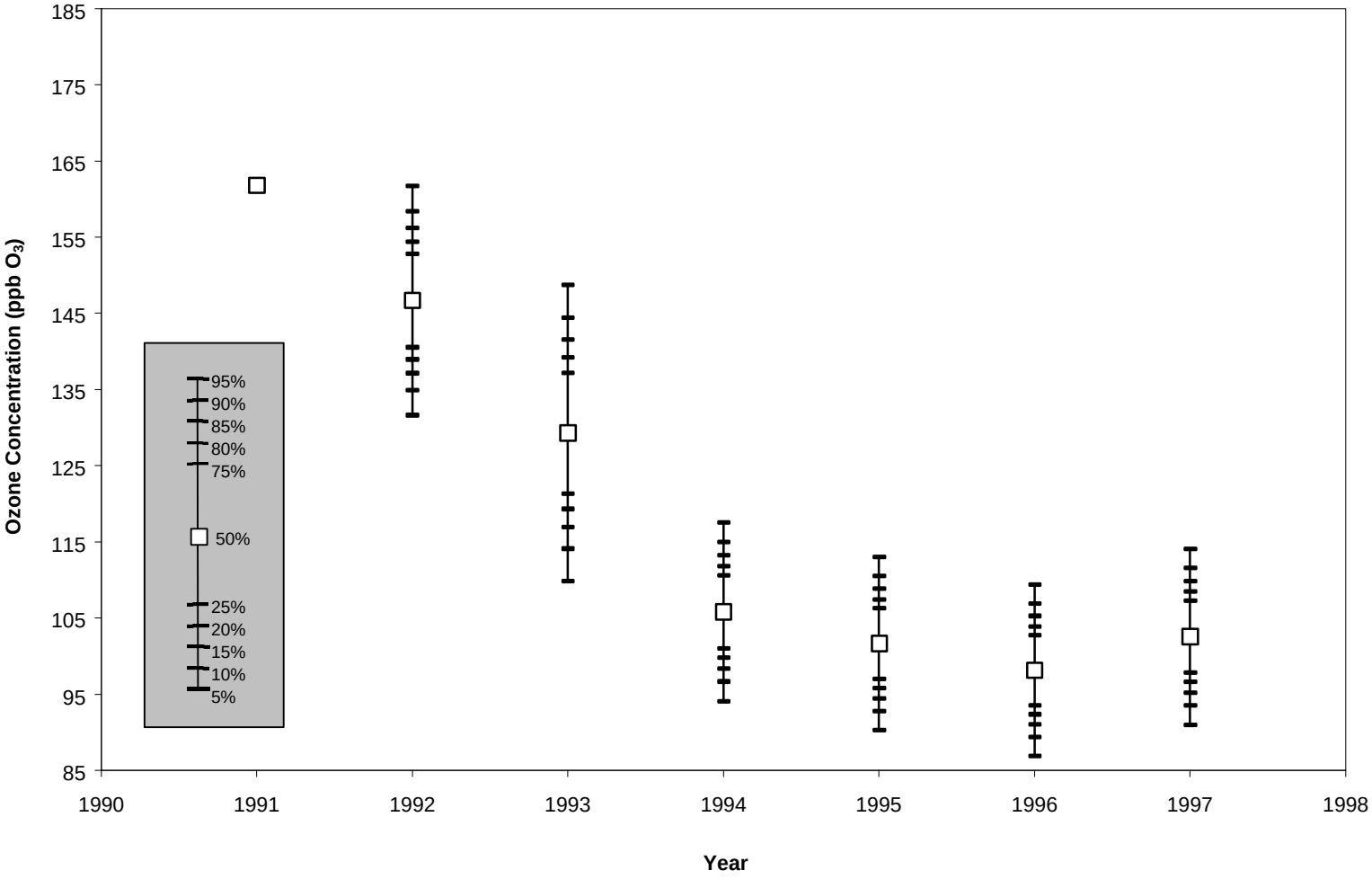

Figure 8-12. EPDC using native variability techniques for the San Diego 12th Street site.

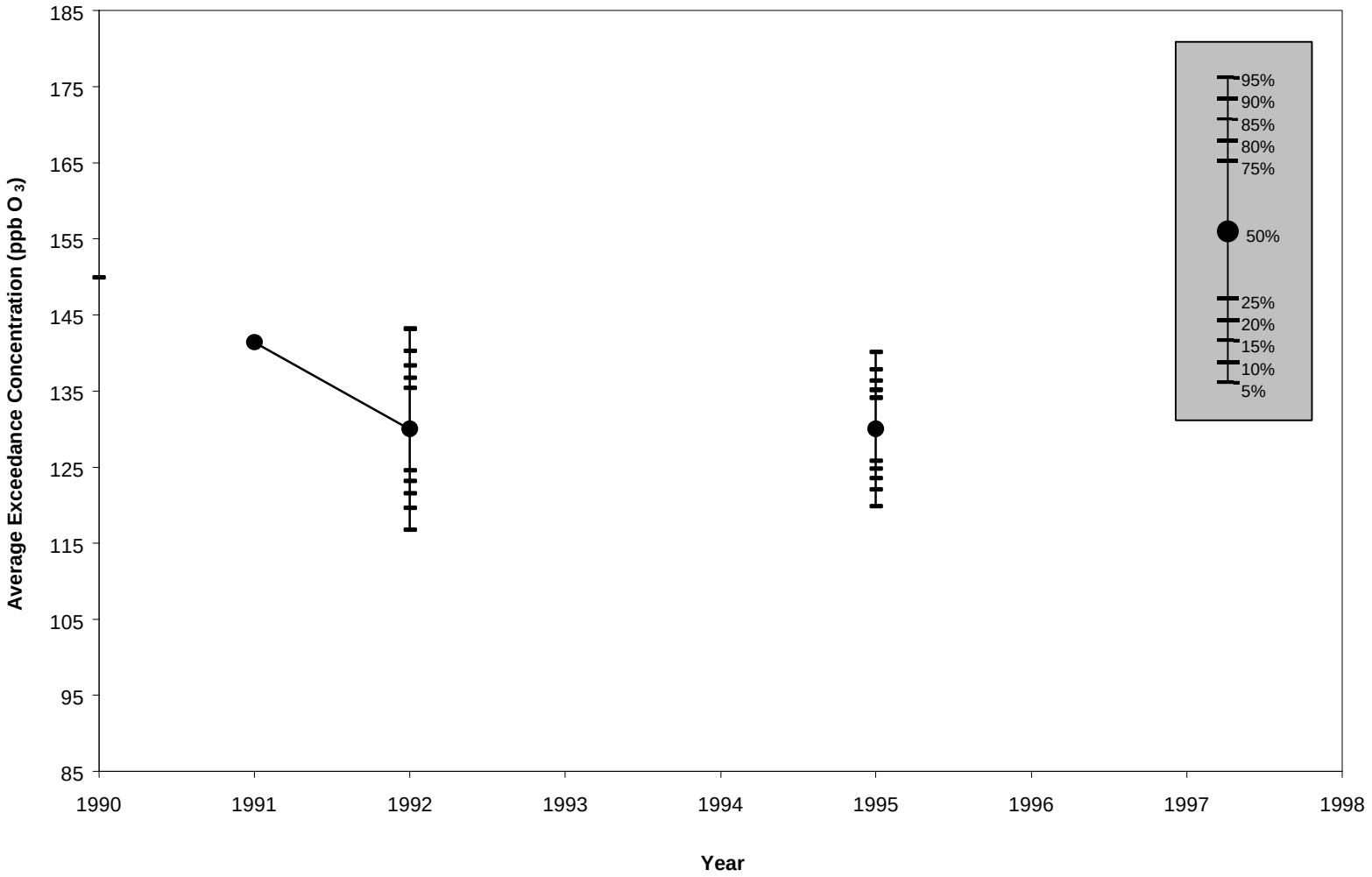

Figure 8-13. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the San Diego 12th Street site. Averages were not determined for the years in which there were no exceedances of the 1-hr Ozone NAAQS.

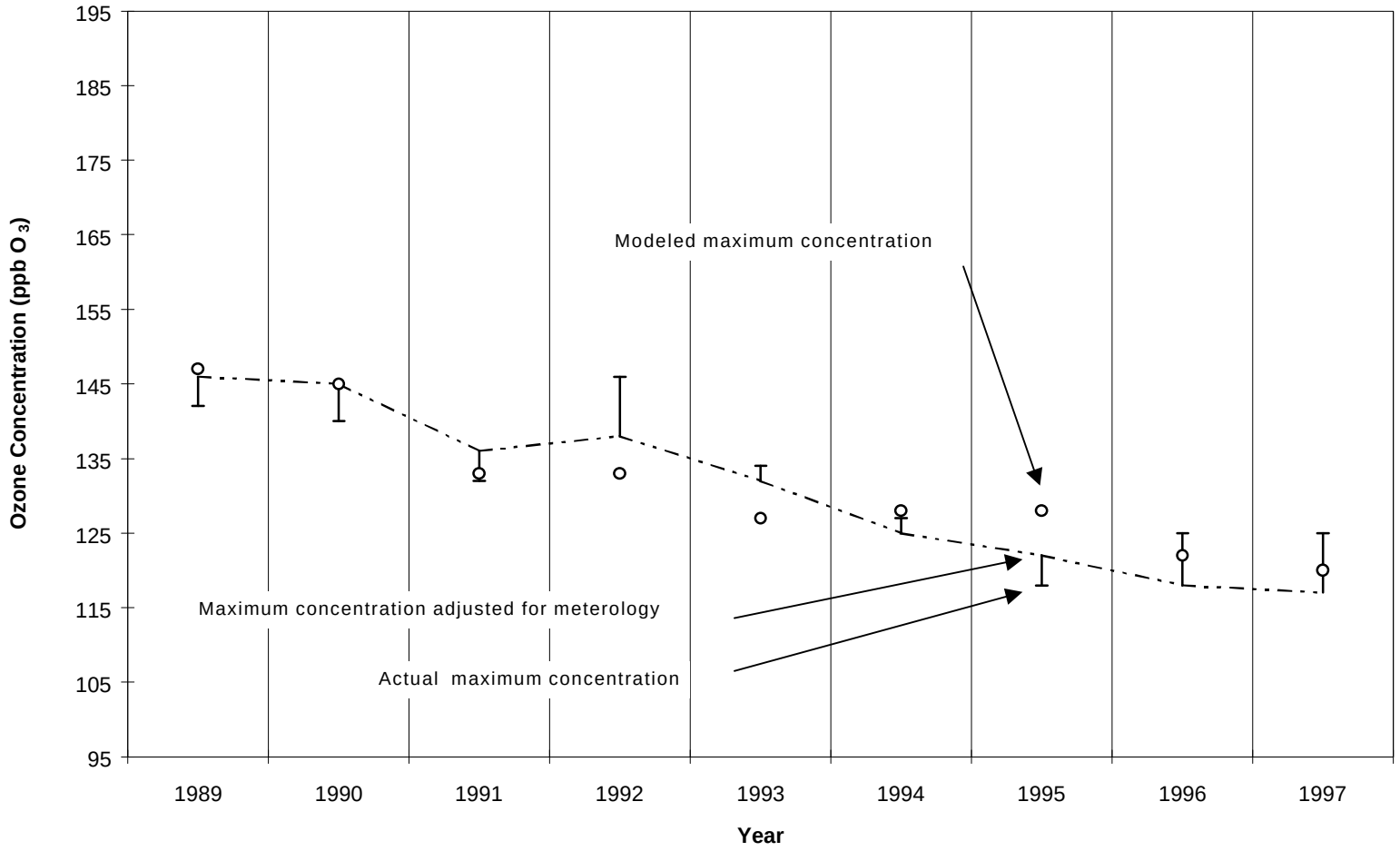

Figure 8-14. Meteorology adjustment of the maximum ozone concentrations using the Cox and Chu probability distribution technique for a site in the San Diego MSA.

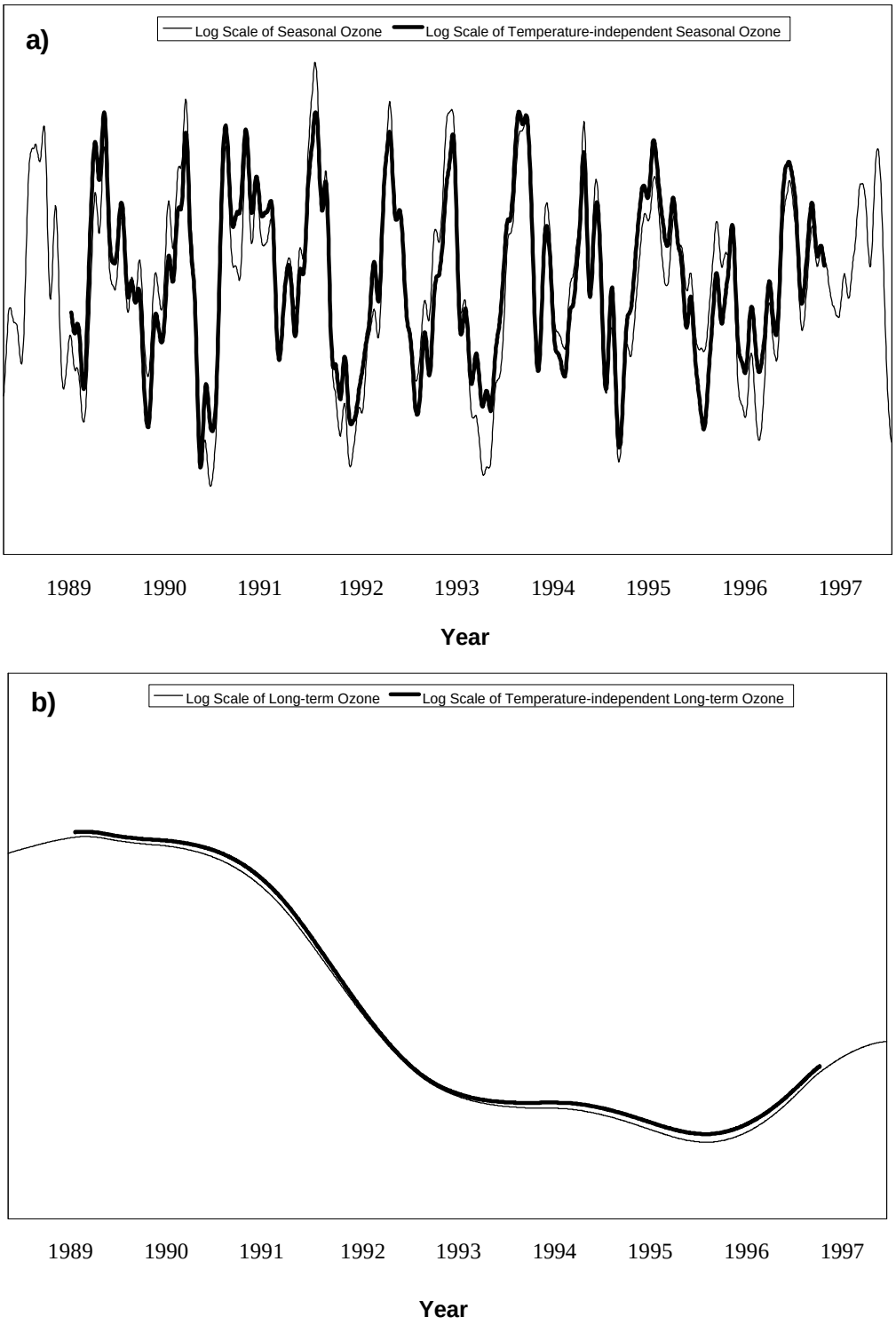

Figure 8-15. Meteorology adjustment of San Diego ozone concentrations using the Rao and Zurbenko filtering technique: a) seasonal component of ozone concentrations and b) long-term component of ozone concentrations (Steven Porter, Department of Civil Engineering, University of Idaho, Idaho Falls, Idaho, 1999).

Table 8-1. Summary of statistical and adjustment analyses performed on data from the San Diego 12th Street.

Statistical Analyses	Trend in 1989-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward Inconclusive
Running 3-yr average of exceedance concentration	Downward
Total number of exceedances	Downward
Maximum concentrations	Downward
Number of exceedances by meteorology	Inconclusive
Cumulative population-weighted exposure hours	Downward
Morning precursor concentrations	Inconclusive
Morning VOC/NO_x ratios	Inconclusive
Adjustment Analyses	**Trend in 1989-1997 Ozone**
Expected peak day concentrations	Downward
Native variability of average daily maximum ozone concentrations	Downward
Native variability of average exceedance concentrations	Inconclusive
Meteorological adjustment using probability distribution (Cox and Chu)	Downward
Meteorological adjustment using filtering techniques (Rao and Zurbenko)	Downward

9. VENTURA TRENDS IN OZONE

9.1 OVERVIEW

The air quality at the PAMS Type 1 Emma Wood Beach, PAMS Type 2 El Rio, and PAMS Type 3 Simi Valley sites in Ventura County was analyzed using several statistical and adjustment techniques. Exceedances of both the California Ozone Standard and the 1-hr Ozone NAAQS were considered in the analyses. **Figure 9-1** shows the number of exceedance days and the average concentration of the exceedances of the California Ozone Standard for all three sites from 1987 to 1997. **Figure 9-2** shows the number of exceedance days and the average concentration of the exceedances of the 1-hr Ozone NAAQS for all three sites from 1987 to 1997. These figures illustrate that there was considerable variability in the average exceedance concentrations especially when the 1-hr Ozone NAAQS was considered. A decrease in the number of exceedance days at the sites occurred; this was especially clear when the California Ozone Standard was considered.

The Simi Valley site is classified as a PAMS Type 3 site. This site is the focus of this discussion because of its designation as a maximum ozone concentration site. The analyses involving exceedances of the 1-hr Ozone NAAQS at the Simi Valley site are given special attention in this section; the analyses involving the California Ozone Standard and the analyses of the El Rio and Emma Wood Beach sites are presented in Appendix G.

The Simi Valley site presents several possible issues that could affect an analysis of trends:

- Reporting units changed from pphm to ppb on December 31, 1992.
- Simi Valley temperature measurements were unavailable from 1987 to 1990 and in 1990 and 1997. Simi Valley temperature measurements were incomplete in 1996.
- NWS station temperature measurements were not available to supplement the Simi Valley measurements; therefore, trends involving temperature were not performed for the Simi Valley site.

The El Rio site is classified as a PAMS Type 2 site (maximum precursor emissions). This site is discussed to learn about the influence of emissions on the observed ozone concentrations. This site presents the following issues that could affect an analysis of trends:

- El Rio did not experience any exceedances of the 1-hr Ozone NAAQS in 1990 and 1991 and from 1994 to 1997.
- NO_x and hydrocarbon measurements were only available from 1995 through 1997.

Several statistical analyses of the ozone air quality at these sites were performed, and the analysis uncertainty was used to interpret the trends. The ARB performed a statistical analysis of the total exposure hours for the broader Ventura County Air Pollution Control District, and that analysis is also discussed in this section.

ARB adjustment techniques that do not specifically adjust ozone concentrations for meteorological parameters (e.g., EPDC and native variability estimates) were applied to the Simi Valley ozone concentrations to elucidate the effect of atmospheric and meteorological variability on changing ozone concentrations at the site. It was expected that the variability would add an additional uncertainty to the trend analyses. Adjustment techniques that were performed by Cox and Chu and Rao and Zurbenko for the Simi Valley site were not performed due to a lack of complete temperature measurements. The findings of the ARB adjustment techniques are discussed in terms of the statistical analyses (Section 9.2) to establish a consensus among the different analysis approaches.

9.2 STATISTICAL ANALYSES

The statistical analyses of the Simi Valley air quality revealed a decrease in ozone concentrations from 1987 to 1997 as measured by the following indicators: the number of exceedance days, the highest daily maximum ozone concentration, and the cumulative exposure hours. The analyses also identified 1992, 1993, and 1997 to be years during which the number of exceedances and ozone concentrations were dramatically reduced at the Simi Valley site. Some statistics did not reveal clear trends and were also subject to large analysis uncertainties, including the average exceedance concentration and 3-yr running average exceedance concentration. The analysis of average ozone concentrations and precursor concentrations at the PAMS Type 2 El Rio site did not reveal any correlation between the observed daily maximum ozone concentrations and precursor concentrations.

9.2.1 Average exceedance concentration

Figure 9-3 shows the distribution of the daily maximum ozone concentrations at the Simi Valley site from 1987 to 1997. Figure 9-3a shows that the bulk of the daily ozone concentrations (i.e., interquartile range) were below the 1-hr Ozone NAAQS threshold concentration and that the median ozone concentrations varied over the time period. Figure 9-3 demonstrates that the daily maximum ozone concentrations experienced at the site in 1992, 1993, and 1997 were lower than average and that the daily maximum ozone concentrations in 1988 were higher than average. Figure 9-3c demonstrates that the interquartile ranges of the ozone concentrations in 1992, 1993, and 1997 were smaller; this finding suggests that high exceedance concentrations were less common in these years than they were in other years.

Figure 9-4 shows the average exceedance concentrations at the Simi Valley site and the analysis uncertainties that should be used to interpret the trends in concentration. Long-term trends in the average exceedance concentration that were suggested in Figure 9-3 are not distinguishable when the analysis uncertainty of the exceedance concentrations is considered. However, a slight reduction in the average concentration of the exceedances of the 1-hr Ozone NAAQS is observable in 1992, 1993, and 1997. The reduced average concentration of the exceedances in 1997 is typical for many of the other selected PAMS sites in California.

9.2.2 Running 3-year average of exceedance concentration

The running 3-year average concentrations of the 1-hour Ozone NAAQS exceedances are shown in Figure 9-4. The figure illustrates that the average exceedance concentrations are stable over the entire time period when the effects of anomalous ozone events are reduced by distributing the exceedances over a longer time period. Although the stability in the 3-year average exceedance concentration is consistent with the inability to draw trends in the average exceedance concentration when the analysis uncertainty was considered, this could also suggest that anomalous events (such as atypical meteorological events) are responsible for the variations in the average exceedance concentrations in 1992, 1993, and 1997.

9.2.3 Total number of exceedances of the standard

Although the average exceedance concentration did not dramatically change from the late 1980s to the late 1990s, the number of exceedance days definitely decreased. This finding is demonstrated in **Figure 9-5**. This figure also demonstrates that the number of exceedance days associated with daily maximum ozone concentrations that were above 140 ppb decreased from 1987 to 1997. Exceedance concentrations above 160 ppb were uncommon after 1989. Exceedance concentrations above 180 ppb were not observed after 1989.

Figure 9-5 also demonstrates that there were uncommonly few exceedances of the 1-hr Ozone NAAQS in 1992, 1993, and 1997. It is difficult using just this analysis to assess whether the lack of exceedances in these years is due to anomalous events or a long-term improvement in the air quality in Ventura.

9.2.4 Identification of the highest exceedance concentrations

Figure 9-6 shows the top three exceedance concentrations that occurred at the Simi Valley site. This figure illustrates that the highest daily maximum ozone concentrations decreased from 1987 to 1997. This figure also demonstrates that the highest exceedance concentrations were closer to the average exceedance concentration during the years with fewer exceedances (e.g., 1992, 1993, and 1997). The highest exceedance concentrations were much greater than the average exceedance concentrations during years with more exceedances and higher average exceedance concentrations (e.g., 1988, 1989, and 1995). This suggests that the years with fewer exceedances and lower exceedance concentrations are more representative of typical (i.e., average) air quality at the Simi Valley site.

9.2.5 Daily maximum ozone concentration by day of week

When the number of exceedance days by day of week was investigated (**Figure 9-7**), fewer 1-hr NAAQS exceedances occurred on Mondays, Tuesdays, and Sundays. However, when lower thresholds were considered in this analysis, no trend was observed. This suggests

that, statistically, there was no greater chance on any given day of exceedances of the California Ozone Standard.

9.2.6 Spatial distribution of exceedances

A comparison of the number of exceedances and average exceedance concentrations at the three sites in Ventura County (Figures 9-1 and 9-2) revealed several interesting features:

- The average 1-hr NAAQS exceedance concentrations varied considerably at the PAMS Type 1 Emma Wood Beach, PAMS Type 2 El Rio, and PAMS Type 3 Simi Valley sites.
- All three sites experienced decreasing trends in the number of 1-hr NAAQS exceedance days from 1987 to 1997.
- The sites did not necessarily behave similarly on a year-to-year basis. For example, in 1987, 1992, and 1993, fewer 1-hr NAAQS exceedances and lower maximum daily ozone concentrations occurred at the Simi Valley site when higher numbers of exceedances occurred at the El Rio and Emma Wood Beach sites.
- The expected relationship between the different types of PAMS sites was not consistently observed. As expected, the PAMS Type 3 site experienced higher average exceedance concentrations and numbers of exceedances than the other sites (see Figure 9-1). However, the PAMS Type 1 site experienced a slightly higher number of exceedances in 1996 and average exceedance concentrations in 1995 than the PAMS Type 2 site.

The variability in the ozone concentrations at the three sites makes it difficult to assess the impact of regional transport on air quality in Ventura.

9.2.7 Cumulative population-weighted exposure hours

Figure 9-8 shows an estimate of the cumulative population-weighted number of hours during which Ventura County is exposed to elevated ozone concentrations. These results were compiled for an internal study performed by Debora Popejoy of the California Air Resources Board in 1998. This statistic consolidates into a single indicator the distribution of exceedances of the California Ozone Standard, the distribution of populations in the area, the number of exceedances, and the concentration of the exceedances.

This broader perspective on air quality suggests that ozone exposure in Ventura County dramatically decreased from 1986 to 1990 and remained fairly level from 1990 to 1996. Figure 9-10 confirms that ozone exposure decreased in 1987, 1990, and 1993 but suggests that the decreases in ozone concentration that occurred in 1992 at the Simi Valley site did not occur across Ventura County. The exposure calculations have not been compiled for 1997 yet. The analysis suggests that when a broader area is considered, the air quality in the Ventura County

air basin improved from the late 1980s to the late 1990s. However, a statistical evaluation of the exposure-hours was not available to assess the errors on the analysis.

9.2.8 Exceedance concentrations as a function of early morning precursor concentrations

Figure 9-9 illustrates that the exceedance concentrations are not clearly related to the average early morning NO_x and VOC precursor concentrations. However, a trend was difficult to establish because concurrent VOC and NO_x measurements were only available from 1995 to 1997 and because the El Rio site did not experience any exceedances of the 1-hr Ozone NAAQS in this same time period. The highest daily maximum ozone concentrations decreased from 1995 to 1997. In contrast, the average early morning VOC measurements and the ratio of VOC to NO_x measurements appeared to increase from 1995 to 1997. The early morning NO_x measurements showed no change. When the uncertainty on the ratios are considered, El Rio appears to move from the VOC-limited regime to the NO_x-limited regime. This analysis suggests that the changes in the ozone concentrations that occurred in 1997 were not the sole result of changing VOC or NO_x concentrations. Other factors, such as the composition of the VOC, may be important.

9.3 ADJUSTMENT ANALYSES

Statistical analyses applied to the Simi Valley site did not reveal clear trends when the analysis uncertainties were also considered. The adjustment techniques applied to the ozone measurements made at the Simi Valley site and discussed in this section were used to assess whether the uncertainty analysis is, in part, the result of variability in the ozone concentrations due to atmospheric or meteorological events. The adjustment techniques were used to estimate the uncertainty in the ozone measurements due to atmospheric or meteorological variability from 1987 to 1997 and differences in meteorology from year to year. It is anticipated that the adjustment techniques will allow for more clear trends to be determined. However, the lack of temperature measurements at the Simi Valley site prevented the Cox and Chu and Rao and Zurbenko analyses from being performed.

9.3.1 EPDCs as a function of early morning precursor concentrations

Figure 9-9 illustrates that the EPDCs are not clearly related to the average early morning NO_x and VOC precursor concentrations. A trend was difficult to establish because concurrent VOC and NO_x measurements were only available from 1995 to 1997. The lack of exceedances at the El Rio site do not impact this analysis because the EPDC statistic is not based on compliance with either of the 1-hr ozone standards. The EPDC were constant from 1995 to 1997. In contrast, VOC concentrations and the VOC-to-NO_x ratios appeared to increase during this time period. Thus, the changing precursor ratio did not appear to affect the EPDC estimates. This suggests that the precursor concentrations were not clearly related to the observed maximum ozone concentration (in terms of the EPDC). This finding is consistent with the conclusions from Section 6.2.8. However, it is expected that the method of

calculating an EPDC will bias against anomalous events on both sides of the spectrum. This is observed in this case where the EPDC in 1997 is much higher than the observed second highest maximum concentrations. This raises questions regarding the evaluation of ozone trends at the Simi Valley site using the EPDC statistic.

9.3.2 Variability of average daily maximum ozone concentrations

The native variability allows the uncertainty in the analysis as a result of atmospheric and meteorological variabilities to be explored. Native variability represents a different kind of uncertainty than the analysis uncertainty that has been used to interpret trends so far. Typically, the native variability is used to interpret trends in EPDC. However, in this report, the concept of native variability was also applied to average daily maximum ozone concentrations. This allows a direct comparison between the uncertainties due to the analysis and the uncertainties due to atmospheric and meteorological variability.

Figure 9-10 demonstrates the native variability about the EPDC for the Simi Valley site. When 95 percent confidence limits are associated with the native variability estimates, significant reductions in ozone concentrations were seen from 1991 to 1997. This figure also suggests that ozone concentrations were most dramatically lowered in 1994. Previous analyses did not identify particularly low ozone concentrations in 1994. However, it is expected that the method of calculating an EPDC will bias against anomalous events on both sides of the spectrum. This analysis also applies native variability principles to EPDCs and is therefore also biased against anomalous events on both sides of the spectrum. The overall trends suggested in the EPDC with native variability limits are consistent with the previous findings that ozone concentrations have dropped from the late 1980s to the 1990s at the Simi Valley site.

Figure 9-11 demonstrates the native variability about the average exceedances of the 1-hr Ozone NAAQS. The trends suggested in this analysis are consistent with the analysis uncertainties that were discussed earlier but are much different than the trends in EPDC observed in Figure 9-10. When 95 percent confidence limits are considered, the ozone concentrations did not decrease dramatically, except in 1997. This suggests that changes in the ozone concentrations from 1987 to 1996 were within the uncertainty due to the native variability of the average ozone concentration.

9.4 SUMMARY OF VENTURA AIR QUALITY TRENDS

Table 9-1 summarizes the findings from statistical and adjustment analyses performed on data from Ventura County. The consensus is that ozone concentrations have declined between 1987 and 1997. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability and meteorology was found to obscure trends.

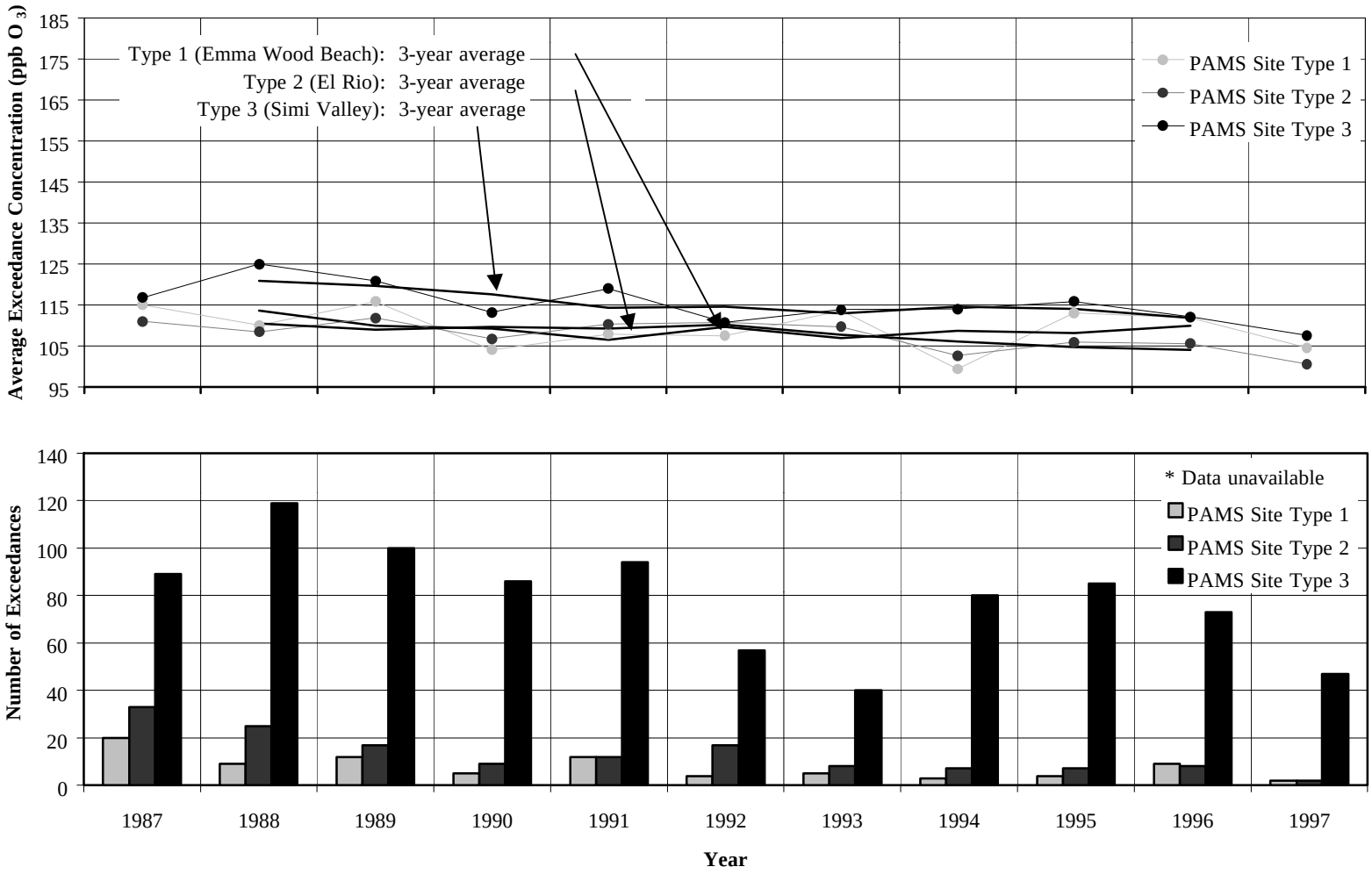

Figure 9-1. Exceedances of the California Ozone Standard at selected sites in the Ventura MSA.

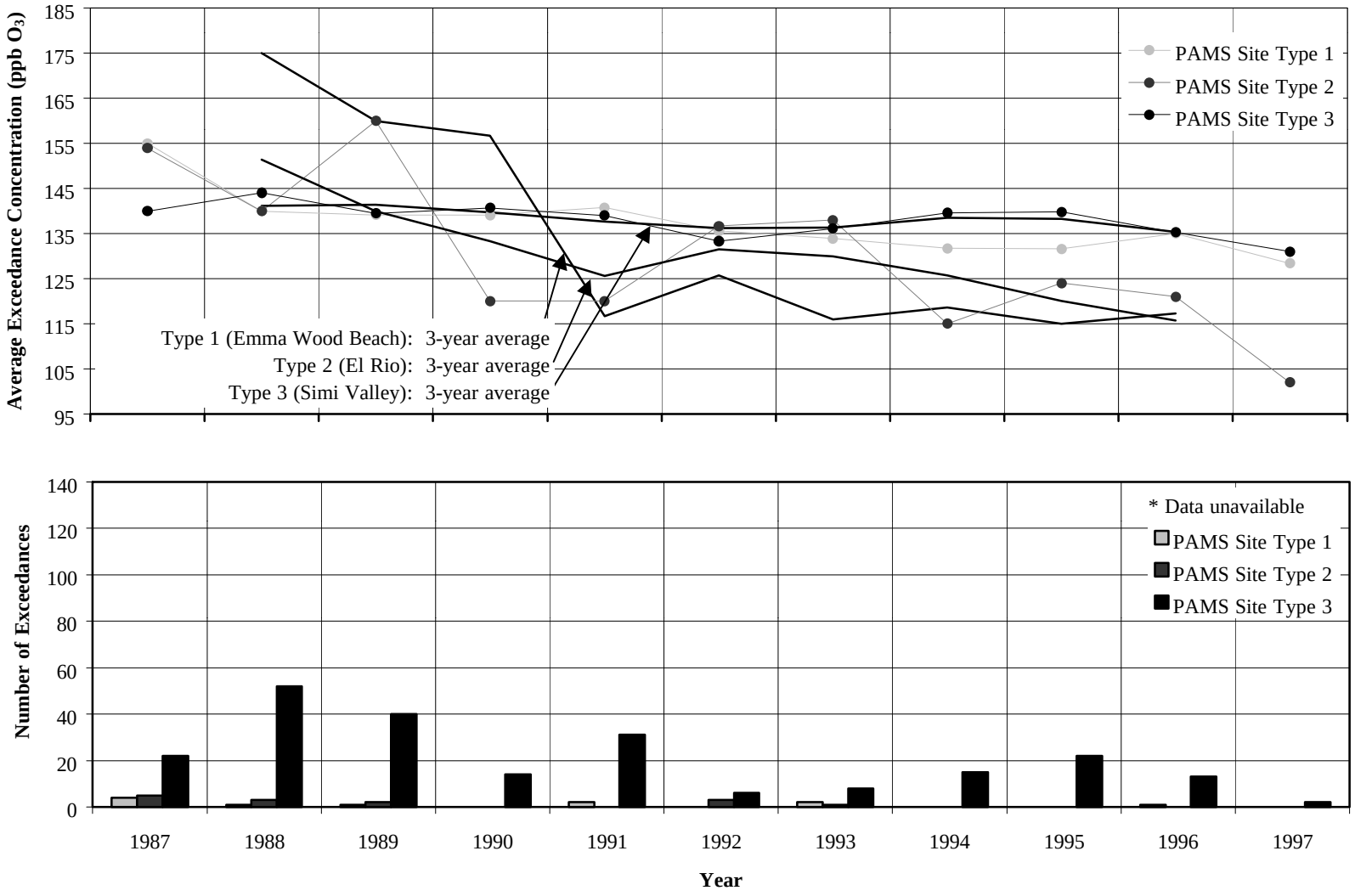

Figure 9-2. Exceedances of the 1-hr Ozone NAAQS at selected sites in the Ventura MSA.

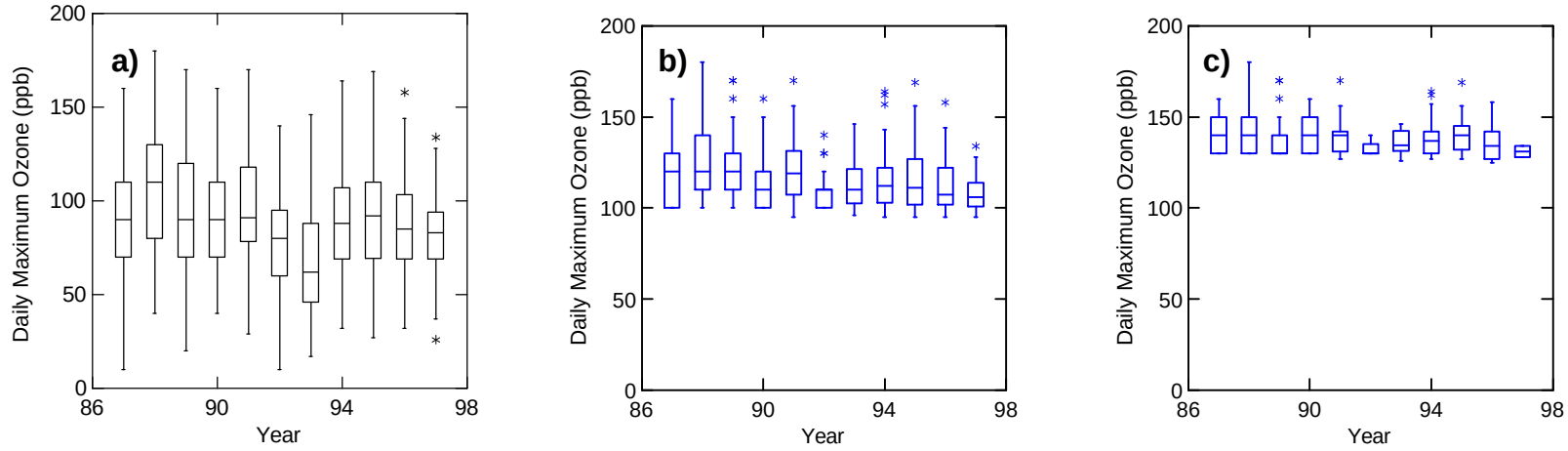

Figure 9-3. Daily maximum ozone concentrations for the Simi Valley site: a) all daily maximum ozone concentrations, b) daily maximum ozone concentrations above the California Ozone Standard, and c) daily maximum ozone concentrations above the 1-hr Ozone NAAQS.

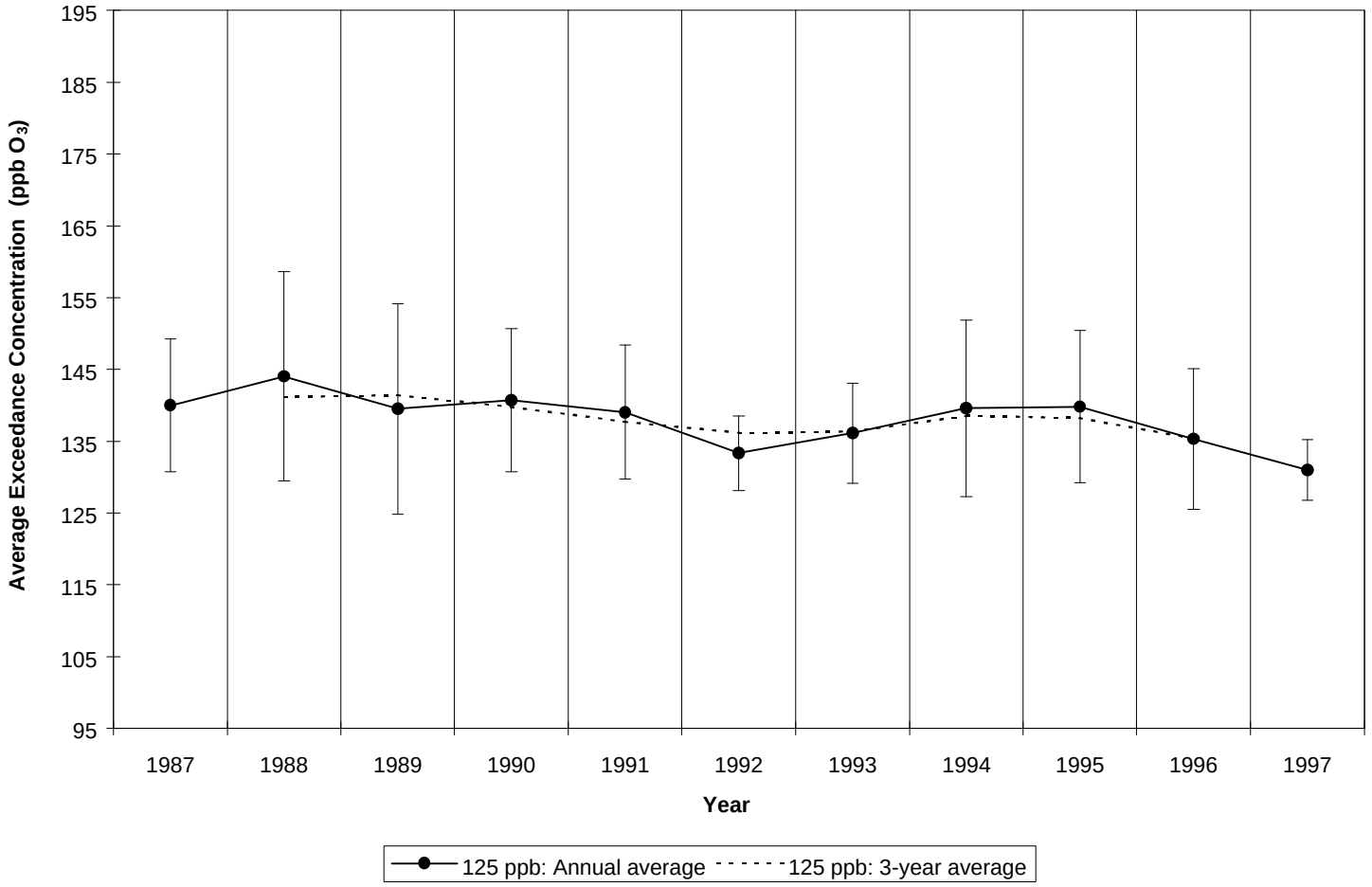

Figure 9-4. Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty for the Simi Valley site. Three-year averages were determined using the highest non-exceedance ozone concentrations in 1989 and 1997 (years in which the 1-hr Ozone NAAQS threshold concentration was not reached). Error bars indicate the analysis uncertainty on the average ozone concentrations.

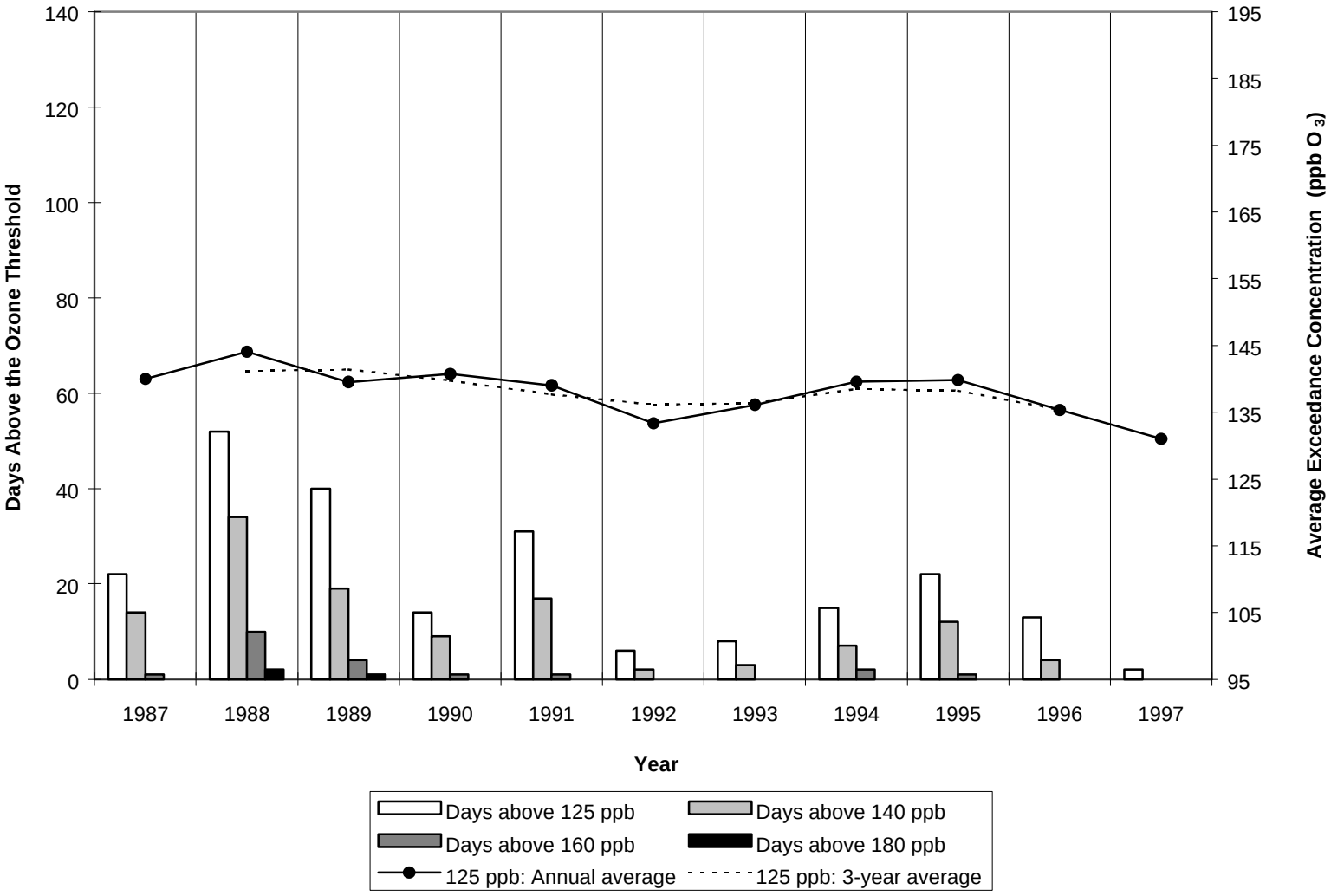

Figure 9-5. Total number of exceedances of the 1-hr Ozone NAAQS the Simi Valley site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

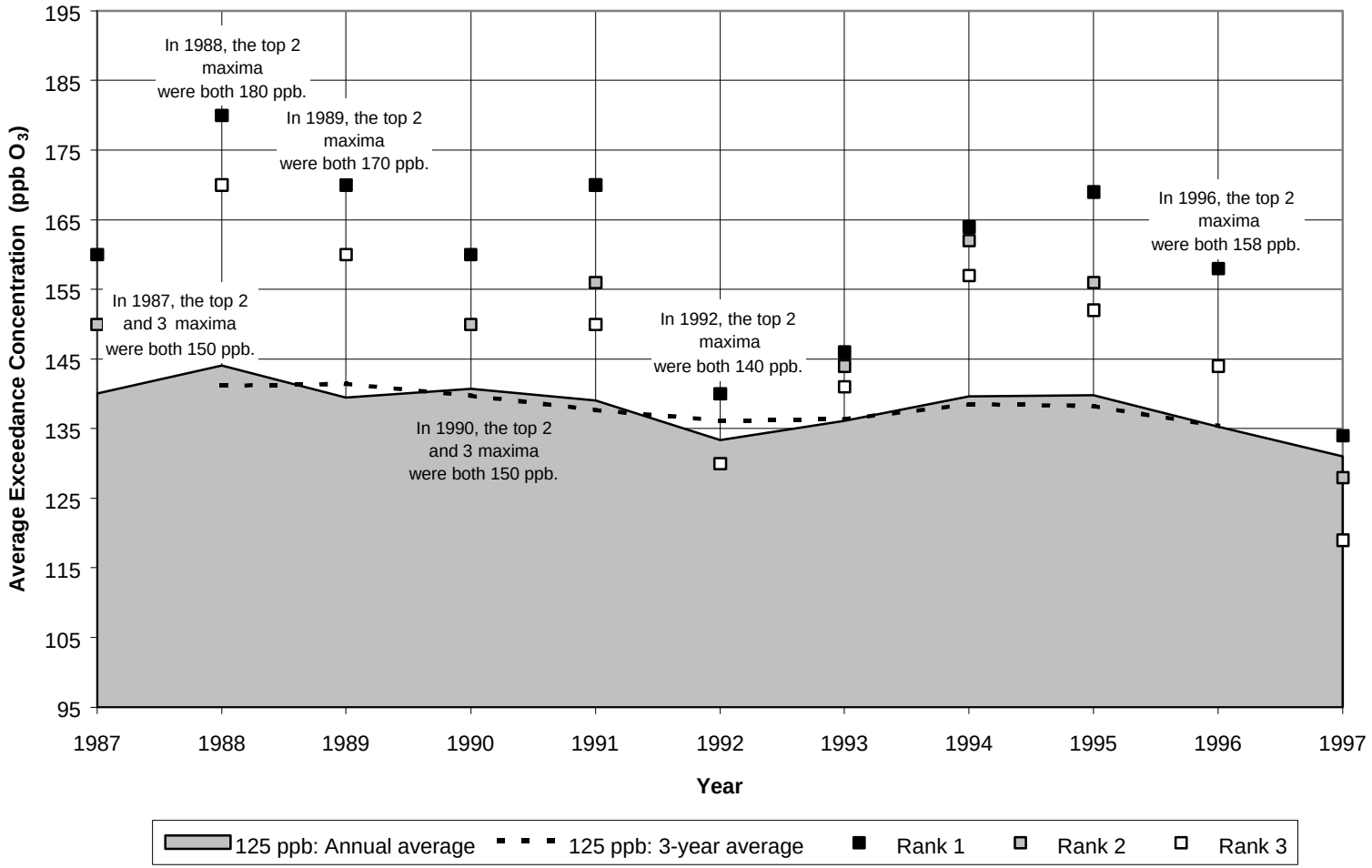

Figure 9-6. Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS for the Simi Valley site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

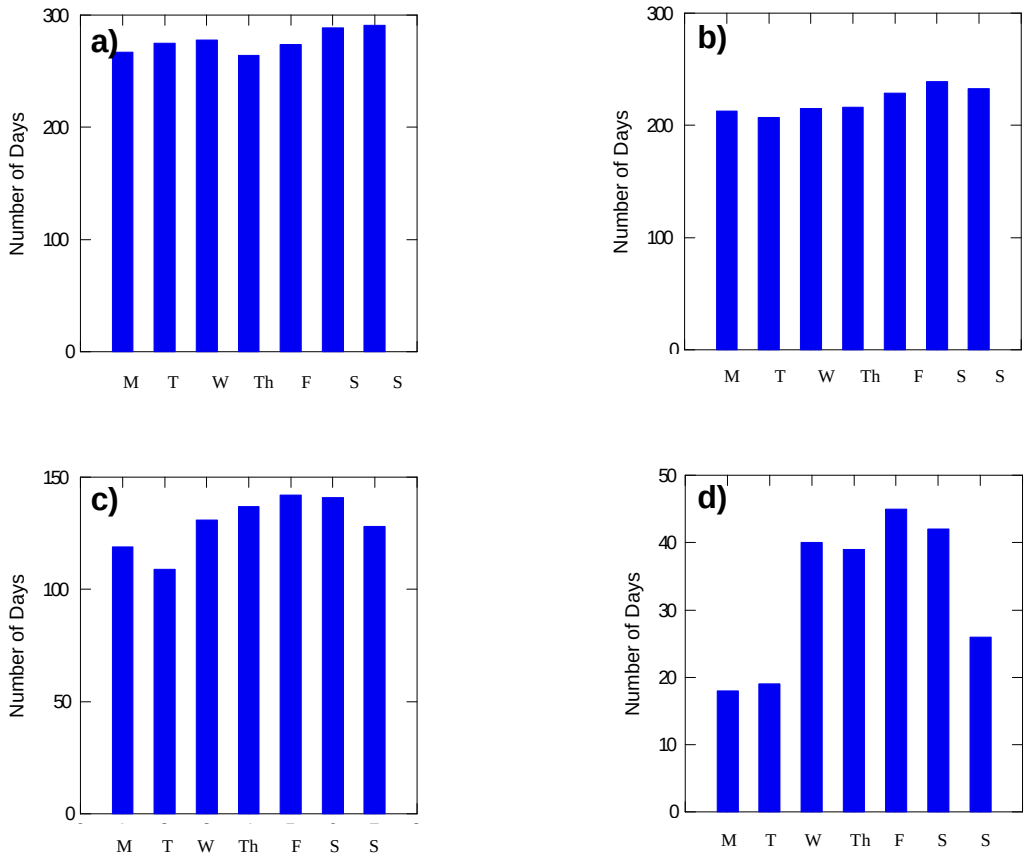

Figure 9-7. Number of days above a threshold ozone concentration by day of week for the Simi Valley site from 1987 to 1997: a) above 70 ppb, b) above 80 ppb, c) above 95 ppb (California Standard), and d) above 125 ppb (1-hr NAAQS).

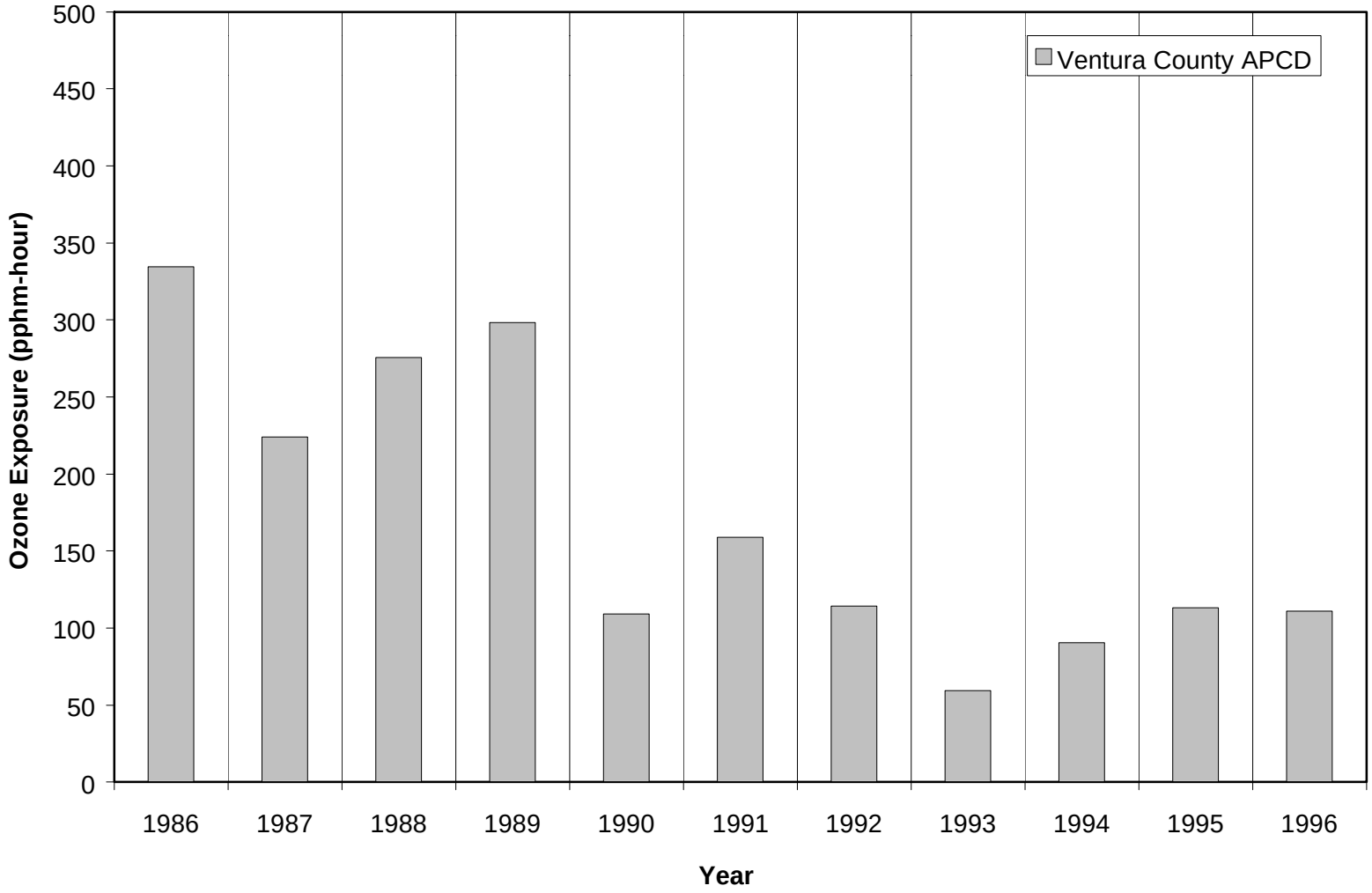

Figure 9-8. Cumulative population-weighted exposure hours of the broader Ventura County Air Pollution Control District to exceedances of the California Ozone Standard.

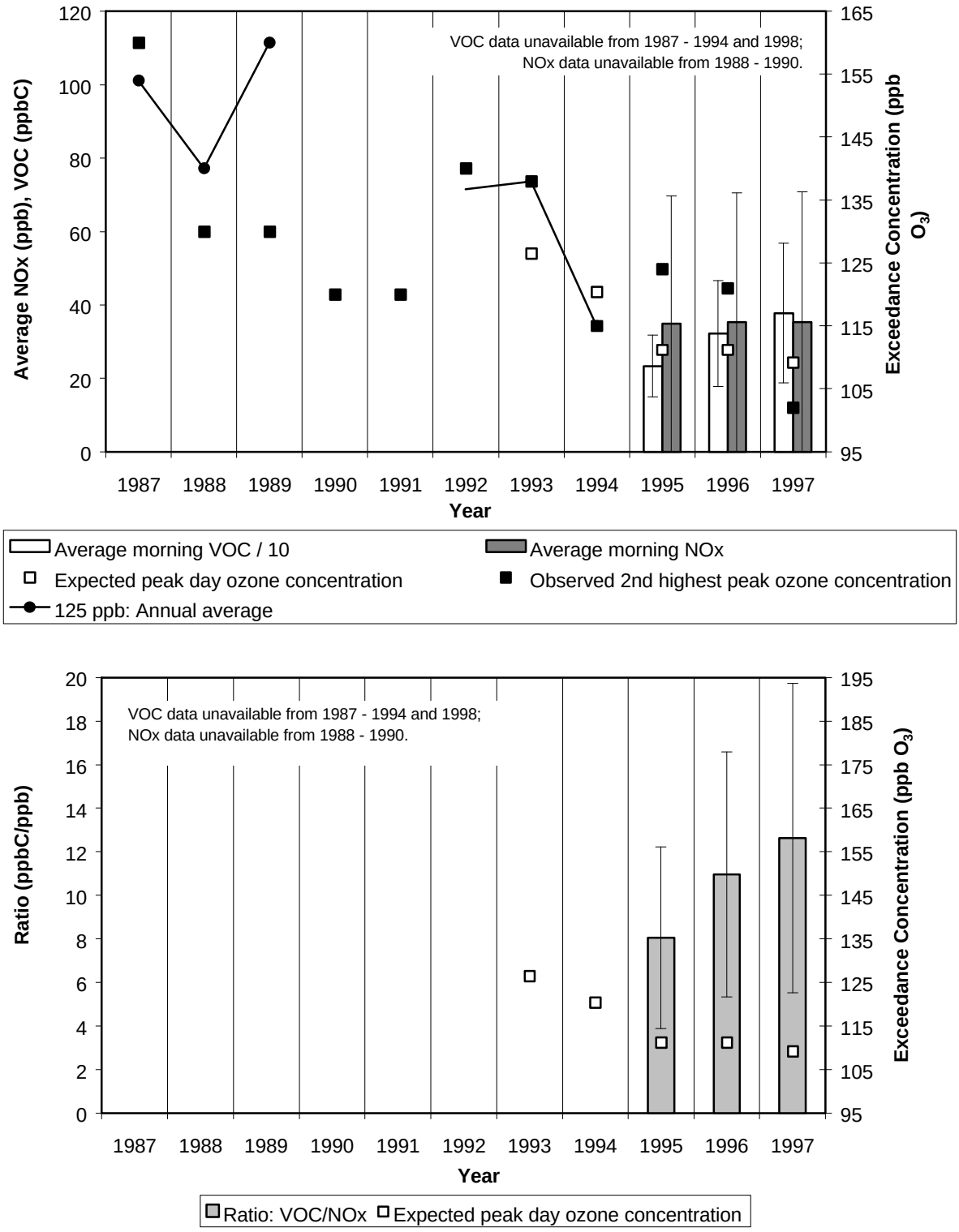

Figure 9-9. Exceedance concentrations of the 1-hr Ozone NAAQS and early morning precursor concentrations for the El Rio1994 site. Three-year averages were determined using the highest non-exceedance concentrations in 1989 and 1997.

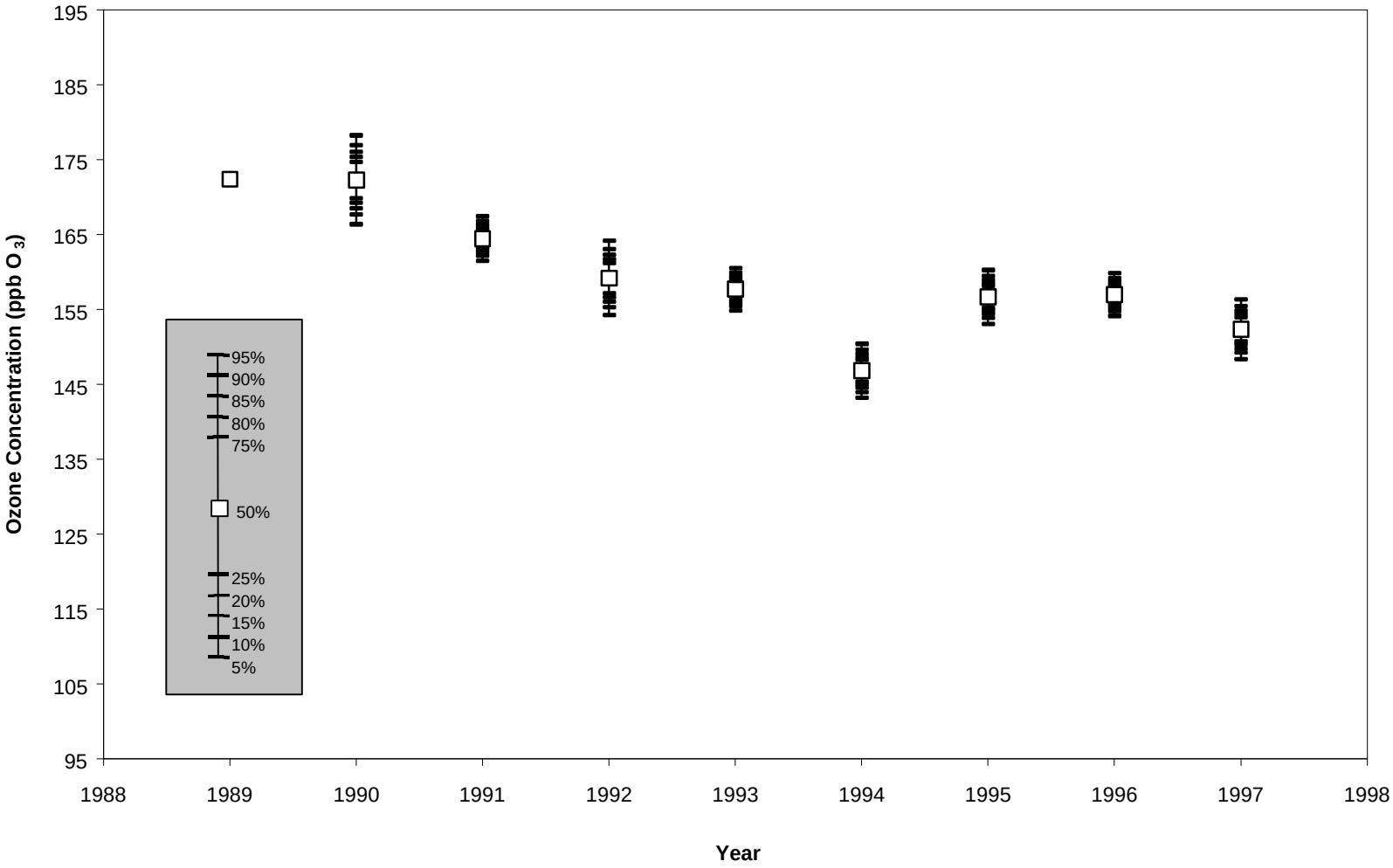

Figure 9-10. Variability of the EPDCs using native variability techniques for the Simi Valley site.

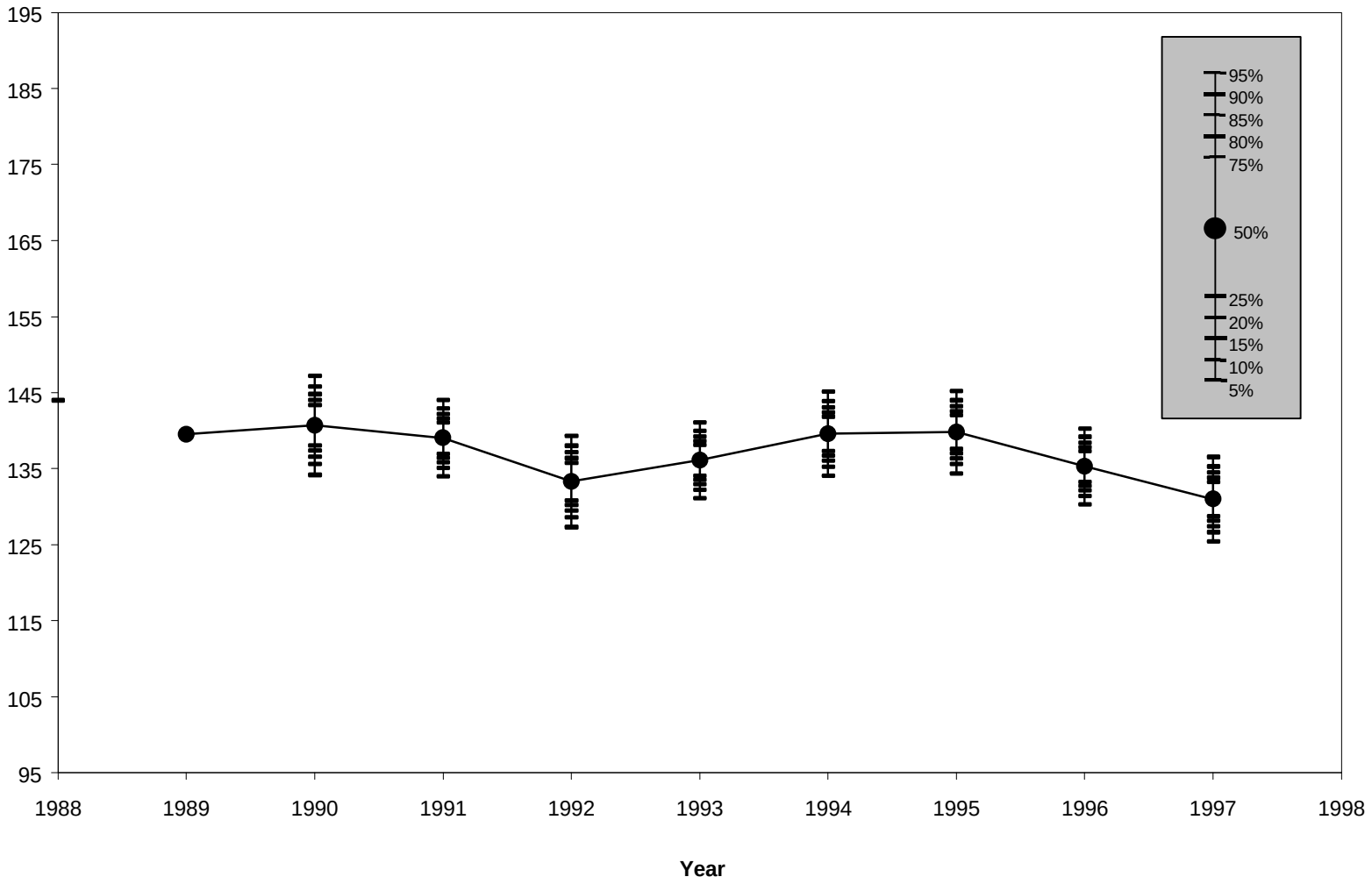

Figure 9-11. Variability of the average 1-hr Ozone NAAQS exceedance concentration using native variability techniques for the Simi Valley site.

Table 9-1. Summary of statistical and adjustment analyses performed on data from Ventura County.

Statistical Analyses	Trend in 1987-1997 Ozone
Average Exceedance Concentration - including uncertainty	Downward Inconclusive
Running 3-yr average of exceedance concentration	Downward
Total number of exceedances	Downward
Spatial distribution of exceedances	Consistent, Downward
Maximum concentrations	Downward
Cumulative population-weighted exposure hours	Downward
Morning precursor concentrations (El Rio)	Mixed
Morning VOC/NO_x ratios (El Rio)	Upward
Adjustment Analyses	**Trend in 1987-1997 Ozone**
Expected peak day concentrations	Downward
Native variability of average daily maximum ozone concentrations	Downward
Native variability of average exceedance concentrations	Inconclusive

10. TRENDS IN VOLATILE ORGANIC COMPOUNDS

10.1 BACKGROUND

In each MSAs, the trends in morning VOC and NO_x concentrations (and ratios) were investigated. In most cases, trends in the precursor concentrations were inconclusive over the data period. However, a major change in VOC composition occurred because of the implementation of reformulated gasoline (RFG). This change provided a unique opportunity to observe the effects on ambient concentrations. To help meet clean air standards, the Clean Air Act Amendments of 1990 (CAAA) required the use of RFG in the nine worst ozone nonattainment areas of the country. The principal differences between Phase I RFG and conventional gasoline include significant reductions in benzene and total aromatic hydrocarbon levels in the fuel, a significant increase in the oxygen content in the fuel and a significant reduction in Reid Vapor Pressure (RVP). Typically, butanes are reduced to decrease RVP. Higher alkanes and aromatics may be added to reduce fuel volatility. Reducing RVP reduces fuel volatility and constitutes the bulk of the hydrocarbon emission reductions achieved through RFG (EPA OMS web page http://www.epa.gov/OMSWWW/rfgnew.htm).

The federal RFG requirement has two key phase-in milestones: Phase I RFG was required to be available at gasoline retail operations beginning January 1, 1995. Phase II RFG, which will require further hydrocarbon and toxic reductions, is required to be available in the year 2000. In addition, California has had separate fuel requirements that also require gasoline reformulation, although California's fuel requirements differ somewhat from federal RFG mandates. Key milestones for both California and federal RFG are shown on **Figure 10-1**. This figure shows the median morning ambient concentrations of benzene in Los Angeles. Actual dates and milestones for RFG implementation include:

- November 1, 1992: implementation of California's Phase 1 gasoline targeted lower RVP.
- January 1, 1995: federal RFG (EPA Phase I) required for sale at the retail level in the nation's nine worst ozone nonattainment areas (including Los Angeles, Orange, Riverside, San Bernardino, Ventura, and San Diego Counties). This fuel targeted lower RVP, the addition of oxygenates, and specific limitations on benzene content in the fuel. The ARB estimated a 9 percent reduction in VOCs.
- June 1, 1996: California's Phase 2 RFG required at the retail level for entire state. This fuel targeted specific limitations on benzene content and RVP.
- January 1, 2000: federal RFG (EPA Phase II) to be implemented in areas previously covered by EPA Phase I.

10.2 INDICATORS

Data used in the VOC trends investigation were obtained from the ARB and were validated and discussed in a companion report (Main et al., 1999). As a part of the

Coordinating Research Council (CRC) Model Evaluation Feasibility Study (Stoeckenius et al., 1995), STI investigated toxic species, hydrocarbon, and carbonyl compound data collected in the South Coast Air Basin (SoCAB) of California from 1990 through 1993 (Main and Roberts, 1994). Using these data, the temporal trends of selected species, species groups, and ratios were evaluated to assess the usefulness of these parameters as indicators of change in motor vehicle fuel composition (Main and Roberts, 1994; Main et al., 1995). Based on predicted changes in the evaporative and exhaust emissions due to the introduction of California Phase I RFG (Ligocki and Yarwood, 1994) and our knowledge of the ambient data quality and availability, this investigation focused on several species, species groups, and ratios (if available). Consensus among several indicators provides more confidence in the study conclusions.

The federal and state RFG regulations call for specific reductions in benzene; thus, the benzene concentration and weight percent in the atmosphere should be reduced. Additionally, the RFG regulations call for reductions in the total aromatic hydrocarbon concentration. Discussions with analysts in California indicate that concentrations and weight fractions of 2-methylheptane (a C8 alkane), added to the California fuels in the past couple of years, (Poore, 1997) may increase because refiners use it as an aromatic hydrocarbon substitute. The RVP reductions required by RFG may be met by the reduction of the butane content. Unfortunately, the PAMS program does not require the measurement of the oxygenate additives MTBE or ethanol. However, i-butene is a thermal decomposition product of MTBE and is measured at some PAMS sites.

Previous investigations have shown that the species fractions (e.g., concentration of an individual hydrocarbon divided by the NMHC) show less variability than the concentrations (e.g., the interquartile ranges were typically smaller on a relative basis). Likely, the fluctuations caused by variations in meteorology (e.g., mixing depth) and emissions rates (e.g., traffic pattern changes) are greater on a concentration basis than on a weight fraction basis because they influence both the individual species and the NMHC. For these reasons, when NMHC data are available, weight fractions are calculated and used for the trend analysis.

The emissions of these compounds usually build up during the morning rush hours when the mixing layer is beginning to form. These emissions react during the next several hours to produce the maximum downwind ozone concentrations at midday. The morning concentrations measured at the PAMS sites were used for the trend analysis since mixing heights are low, concentrations are high, and photochemical reactivity is less important at this time of day.

It is important to consider that there are other sources of these hydrocarbons in ambient air besides motor vehicle emissions. For example, toluene is a commonly used solvent. However, most of the sites studied here were situated in areas with significant motor vehicle emissions.

Table 10-1 summarizes the indicators investigated as a part of a separate study (Main et al., 1998) for data collected between 1993 and 1996. Many of these indicators were investigated from 1990 through 1997.

10.3 RESULTS

Box-whisker plots were used to visualize the ambient data. **Figure 10-2** shows an annotated example of a box-whisker plot. The box shows the 25th, 50th (median), and 75th percentiles. The whiskers always end on a data point, so when the plots show no data points beyond the end of a whisker, the whisker shows the value of the highest or lowest data point. The whiskers have a maximum length equal to 1.5 times the length of the box (the interquartile range or IR). If there are data outside this range, the "outliers" are also further identified with asterisks representing the points that fall within three times the IR and circles representing points beyond this. A simple way to distinguish a trend is to note when the boxes from two years do not overlap. Generally, statistical tests of the means and median values of the two non-overlapping years will show that they are significantly different.

At most of the study sites, ambient benzene concentrations and/or weight percent and other indicators showed significant declines. In other words, there was consensus among several indicators that RFG may have influenced the ambient concentration and composition. Specific findings are as follows:

- Significant decreases in ambient benzene weight fractions occurred after the implementation of RFG. For example, benzene fractions declined significantly after the implementation of RFG in early 1995 at Los Angeles North Main (**Figure 10-3**) and San Diego 12th Street (**Figure 10-4**). Similarly, the benzene-to-acetylene and benzene-to-toluene ratios decreased during the same period. Similar declines after 1995 were observed at Fresno 1st Street (**Figure 10-5**), Clovis (**Figure 10-6**), and Del Paso Manor (**Figure 10-7**). At these sites, RFG was not implemented until early 1996. Benzene concentrations and weight fractions declined at Simi Valley after 1995 (**Figure 10-8**), but the benzene-to-toluene ratio did not show a decline.
- The n-butane weight fraction has declined since 1990 at Los Angeles North Main (**Figure 10-9**) and San Diego 1st Street. The weight fraction of n-butane also declined in Clovis and Del Paso Manor.
- The i-butene weight fraction has increased since 1995 at Los Angeles North Main (Figure 10-9) and San Diego 1st Street.
- Other hydrocarbons did not show similar significant changes (e.g., toluene in Figure 10-9) nor did the total NMHC.

In this investigation and in earlier investigations, concentration data exhibit more variability. This variability hampers our ability to distinguish changes. Statistical tests (e.g., t-tests, Mann-Whitney test) of the benzene data confirmed that the changes were statistically significant. The changes also were coincident with RFG changes.

Vehicle traffic tunnel measurements of VOCs in the Los Angeles and San Francisco areas also show the effects of fuel benzene changes (**Table 10-2**). For example, note that the toluene- and xylenes-to-benzene ratios were higher in 1996 than in 1995. The difference is most likely due to reductions in benzene between these two years. Unfortunately, we do not have 1994 or 1997 data to see more of the trend. In the San Francisco Bay area, the same ratios show a change between 1995 and 1996 coincident with the California Phase 2 changes in fuel. These separate data sets are further evidence that the PAMS and long-term trends data show real changes.

Table 10-3 summarizes the mean benzene concentrations measured on summer mornings and the overall percent change computed using the first and last years data from the the PAMS and long term trend sites. All sites except El Rio showed a significant decline in ambient benzene concentration (summer morning) over the years shown.

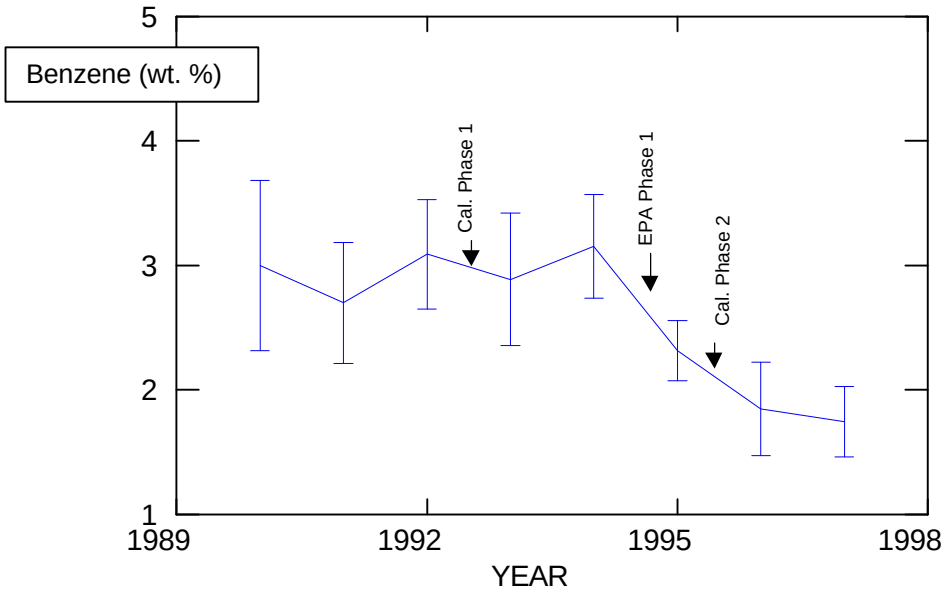

Figure 10-1. Mean and standard deviation of benzene weight percent in Los Angeles (summer morning data) since 1990. RFG milestones are noted on the figure. EPA Phase 1 and California Phase 2 changes specifically targeted benzene content while California Phase 1 focused on reducing fuel volatility.

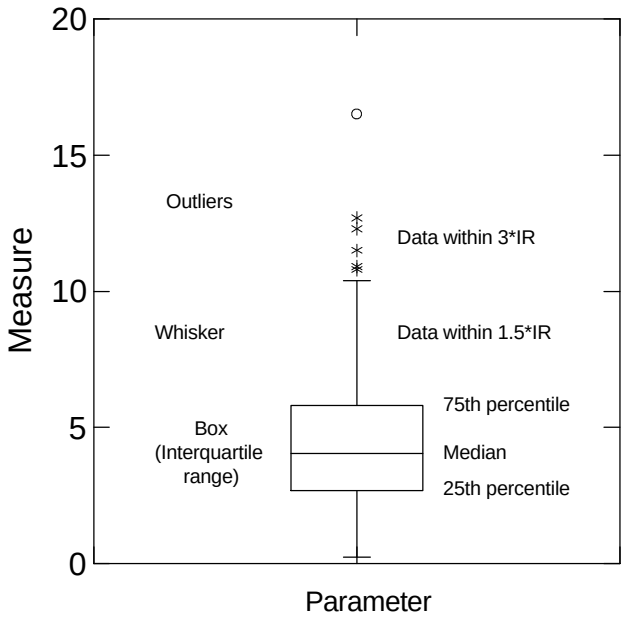

Figure 10-2. Annotated box-whisker plot with outliers.

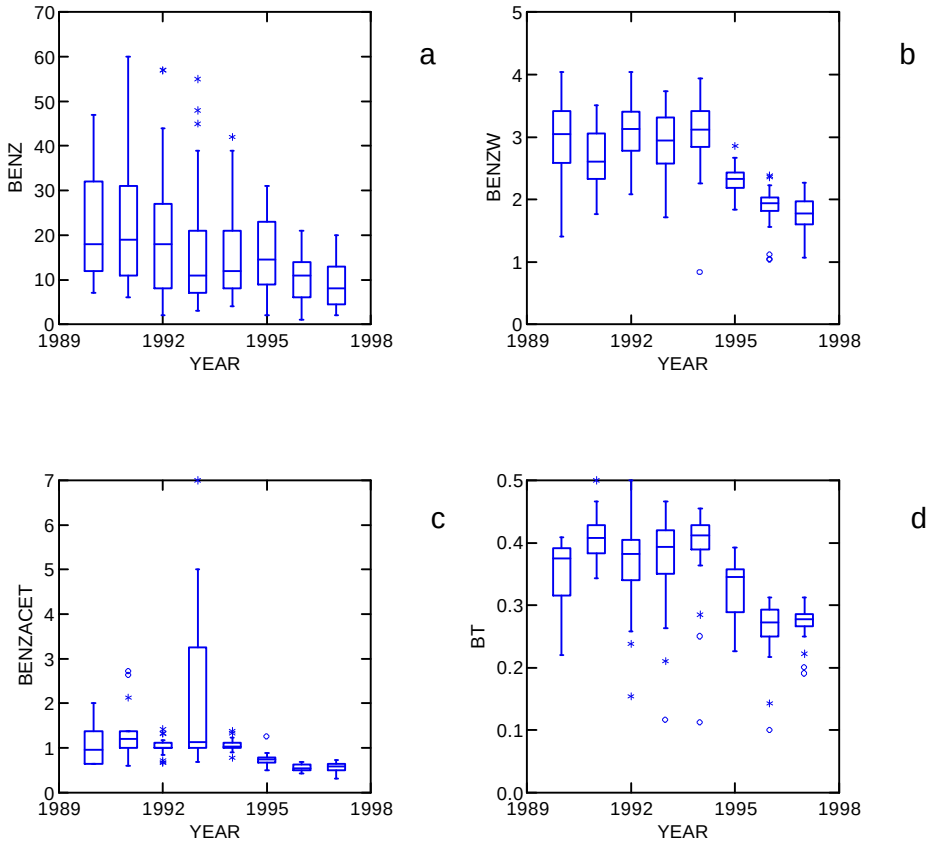

Figure 10-3. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), (c) benzene-to-acetylene concentration ratio (BENZACET), and (d) benzene-to-toluene concentration ratio (BT) at Los Angeles North Main, California, for the summer mornings of 1990-1997. Federal Phase 1 and California Phase 2 RFG changes apply (see Figure 10-1).

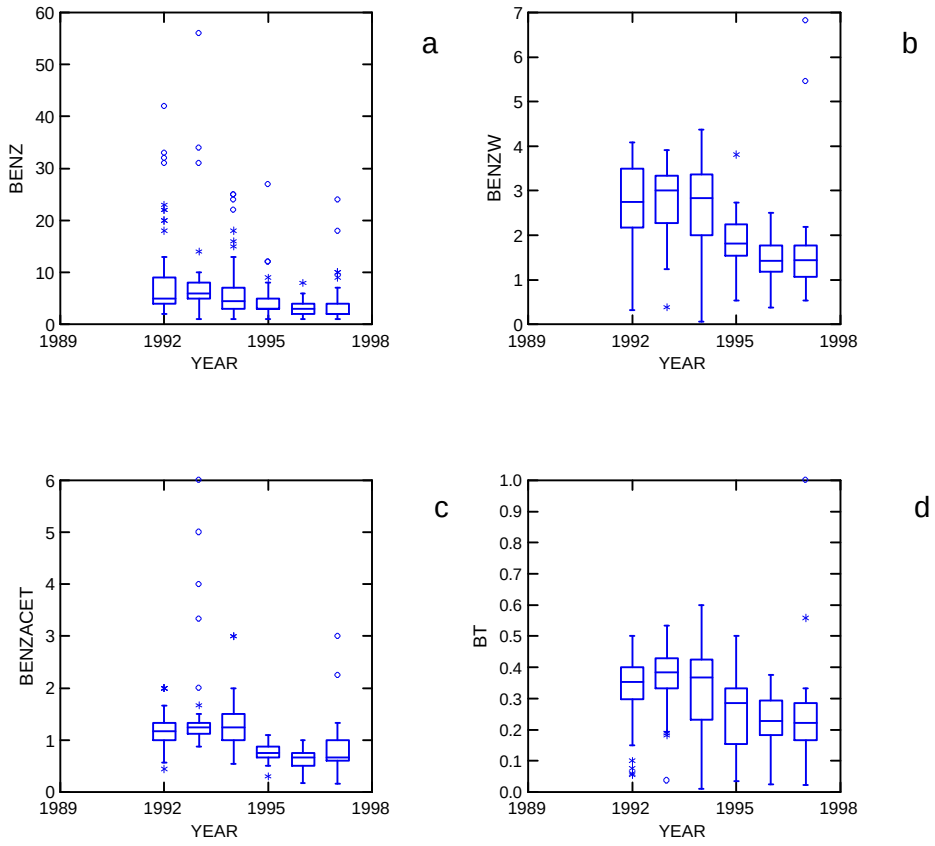

Figure 10-4. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), (c) benzene-to-acetylene concentration ratio (BENZACET), and (d) benzene-to-toluene concentration ratio (BT) at San Diego 12th Street, California, for the summer mornings of 1992-1997. Federal Phase 1 and California Phase 2 RFG changes apply (see Figure 10-1).

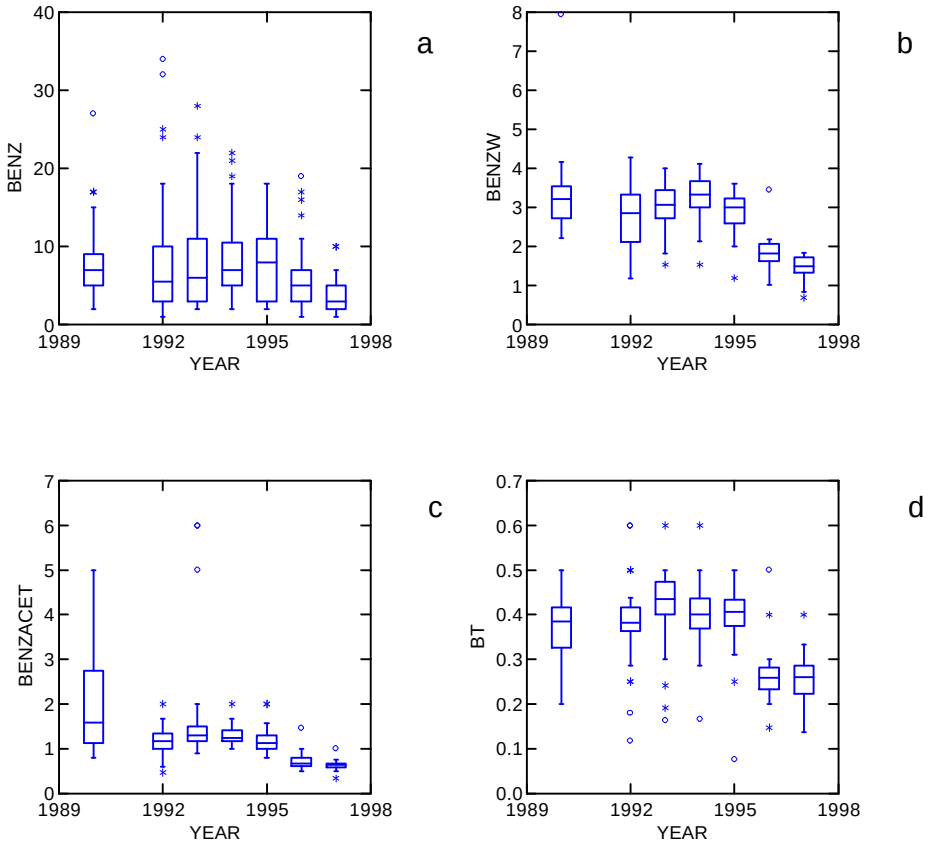

Figure 10-5. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), (c) benzene-to-acetylene concentration ratio (BENZACET), and (d) benzene-to-toluene concentration ratio (BT) at Fresno First Street, California for the summer mornings of 1990-1997. Only California Phase 2 RFG changes apply.

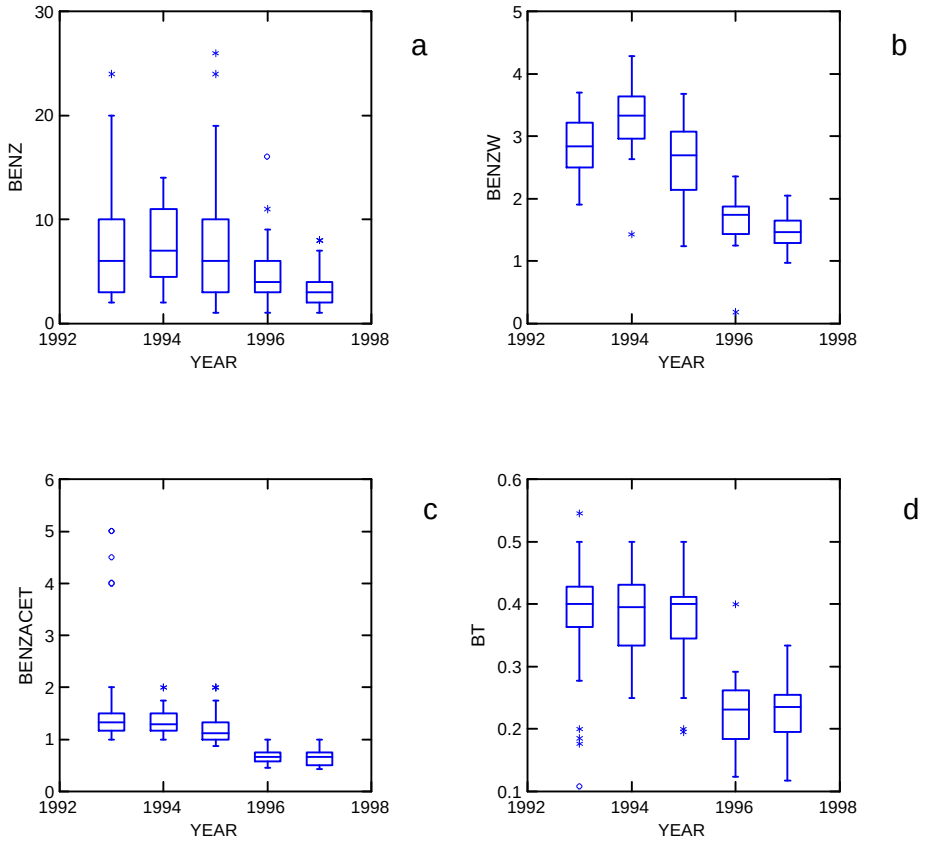

Figure 10-6. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), (c) benzene-to-acetylene concentration ratio (BENZACET), and (d) benzene-to-toluene concentration ratio (BT) at Clovis, California for the summer mornings of 1993-1997. Only California Phase 2 RFG changes apply.

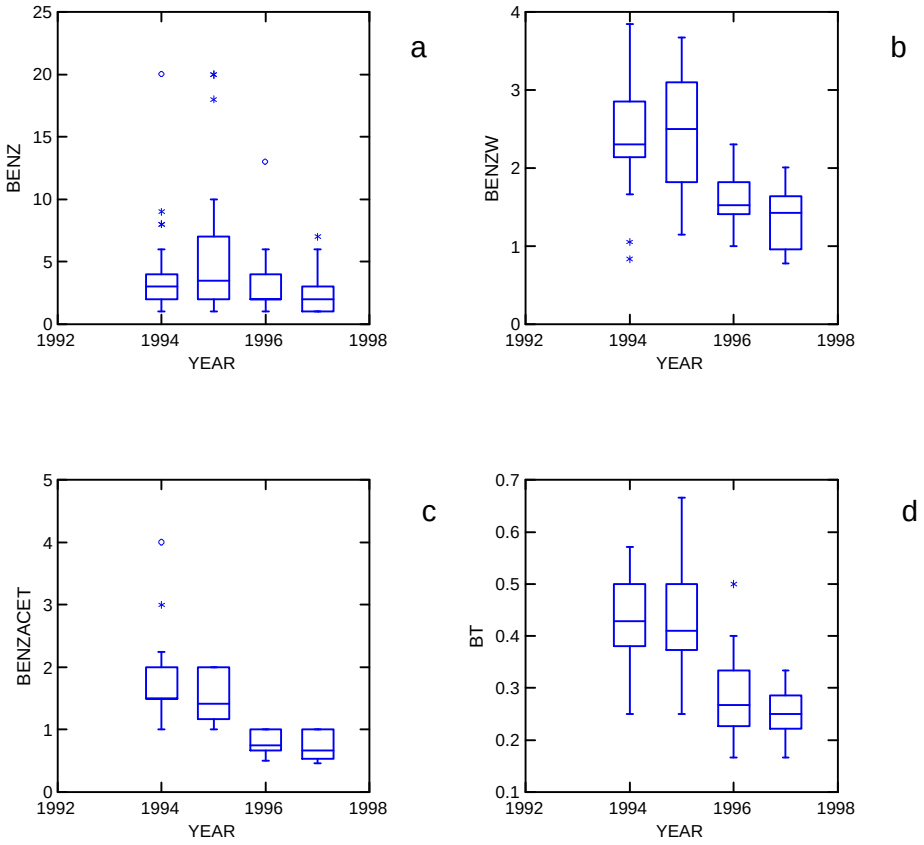

Figure 10-7. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), (c) benzene-to-acetylene concentration ratio (BENZACET), and (d) benzene-to-toluene concentration ratio (BT) at Del Paso Manor, California for the summer mornings of 1994-1997. Only California Phase 2 RFG changes apply.

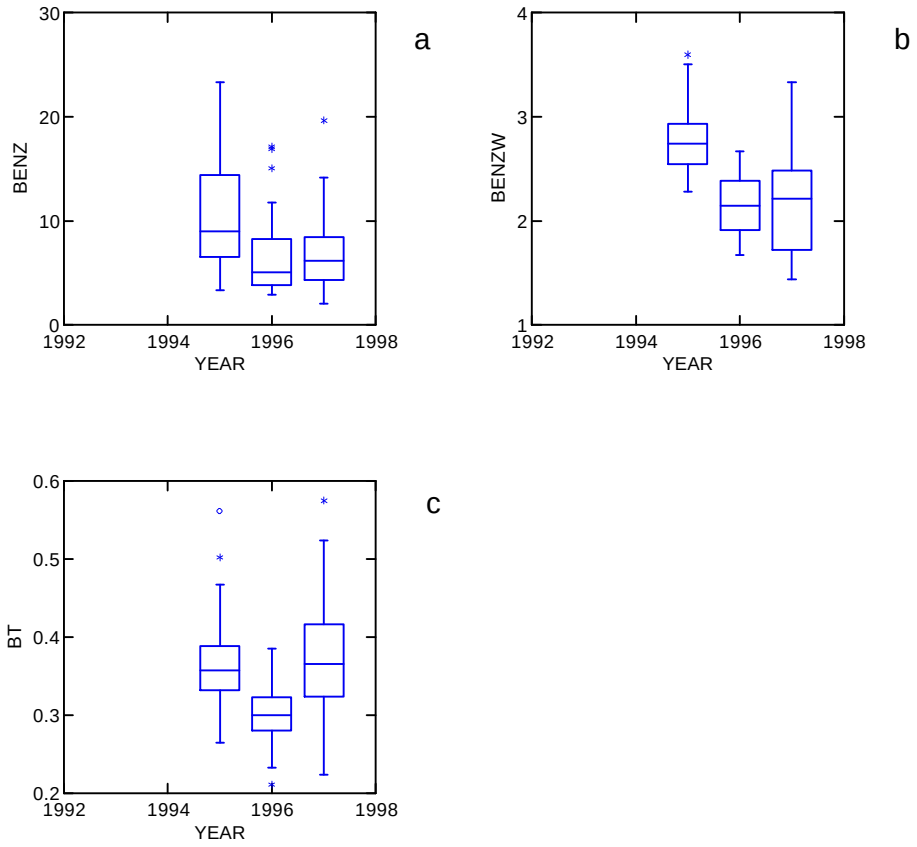

Figure 10-8. Box-whisker plots of (a) benzene concentration (BENZ), (b) benzene weight percent (BENZW), and (c) benzene-to-toluene concentration ratio (BT) at Simi Valley, California for the summer mornings of 1995-1997. Federal Phase 1 and California Phase 2 RFG changes apply (see Figure 10-1).

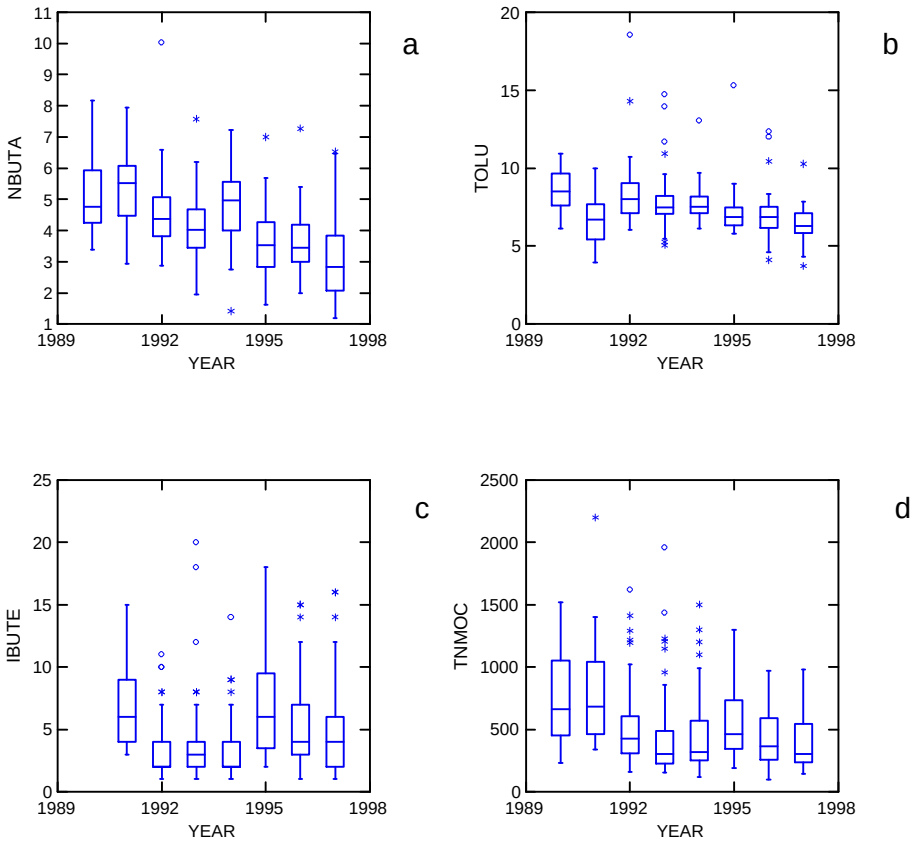

Figure 10-9. Box-whisker plots of (a) n-butane weight percent (NBUTA), (b) toluene weight percent (TOLU), (c) i-butene weight percent (IBUTE), and (d) NMHC concentration (TNMOC) at Los Angeles North Main, California, for 1990-1997. Federal Phase 1 and California Phase 2 RFG changes apply (see Figure 10-1).

Table 10-1. Species (concentration and weight percent of NMHC) and ratios used as possible indicators of RFG implementation (from Main et al., 1998).

Indicator	Motivation
Benzene	Specific reductions called for by RFG regulations.
n-Butane	Normally reduced to lower RVP; RVP needs to be reduced for RFG.
1,3-Butadiene	Modeling studies predict a 20 percent decrease.
Xylenes	An aromatic compound; aromatics need to be reduced for RFG.
Formaldehyde	Modeling studies predict a 20 percent increase.
i-Butene	Decomposition product of MTBE; MTBE is an oxygenate used to meet RFG requirements.
trimethylbenzenes (TMB)	An aromatic compound; aromatics need to be reduced for RFG, particularly C9-C10 aromatics.
C8 Alkanes	Possibly substituted for aromatics to meet RVP reductions.
NMHC	RFG should result in a reduction in the total amount of hydrocarbons.
Benzene/Toluene	If NMHC is not available, this is a good surrogate for the benzene weight percent since toluene is typically measured accurately and does not change as much with RFG as benzene.
n-Butane/i-Pentane	If NMHC is not available, this is a good surrogate for the n-butane weigh percent since i-pentane is not expected to change with RFG.
Benzene/Acetylene	If NMHC is not available, this is a good surrogate for the benzene weight percent since acetylene does not change with RFG and has few sources other than motor vehicle exhaust.
TMB/Toluene	If NMHC is not available, this is a good surrogate for the TMB weight percent since toluene is typically measured accurately and does not change as much with RFG as TMB.
TMB/Xylenes	TMB expected to change more than total xylenes.

Table 10-2. Selected hydrocarbon ratios measured at western urban US tunnels.

Location	Ratio	1994	1995	1996	1997
Sepulveda Tunnel - Los Angeles[a]	benzene/acetylene		0.80	0.53	
	toluene/benzene		2.1	2.5	
	xylenes/benzene		2.2	2.3	
	propene/ethene		0.46	0.50	
Caldecott Tunnel - San Francisco Bay Area[b]	benzene/acetylene	2	1.7	1.1	1.6
	toluene/benzene	1.6	1.6	2.6	2.3
	xylenes/benzene	1.5	1.4	2.0	1.8
	propene/ethene	0.45	0.55	0.59	0.51

a = O'Connor et al., 1998
b = Kirchstetter et al., 1999

Table 10-3. Mean benzene concentrations measured on summer mornings and the overall percent change computed on the first and last years of data from the PAMS and long term trend sites.

Site	1990	1991	1992	1993	1994	1995	1996	1997	% Change
Del Paso Manor					4.1	5.6	2.9	2.4	-42
Arvin						2.0	1.8	1.2	-40
Clovis					7.4	7.8	7.7	4.8	-35
Fresno	7.7		7.5	8.3	8.5	8.1	6.2	3.6	-53
Parlier						4.5	3.3	2.5	-44
Bakersfield					12	13	6.7	4.6	-61
Los Angeles	22	22	21	17	18	16	11	8.8	-60
San Diego			9.4	7.7	8.6	6.5	3.8	4.9	-48
El Rio						3.7	3.7	3.7	0
Simi						11	7.2	7.0	-33

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 CONCLUSIONS

11.1.1 Overview

The goal of this work was to provide direction and training to the Regions and States on the requisite and intricate analyses of the ozone trends at selected PAMS and long-term trend sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura MSAs by performing illustrative analyses. Geography, meteorology, and emissions are all known to influence the ozone formation. However, the relationship between geography, meteorology, emissions, and ozone formation is not well understood. The relationship between variability in atmospheric and meteorological parameters and variability in ozone formation is even less understood. It was anticipated that no single analysis could definitively answer the question "Are ozone concentrations declining in my MSA?". Therefore, long-term trends in ozone were evaluated for each MSA using multiple approaches.

Several statistical methods were employed to determine indicators of long-term trends in ozone and selected ozone precursors at each site within each MSA. The trends of each of the indicators for the PAMS Type 2 and 3 sites and two of the PAMS Type 2-like ARB sites was presented and discussed. In no case did all of the indicators reveal consistent trends in ozone. This finding was not surprising given the variability in atmospheric and meteorological parameters and emissions and the complex relationship between these parameters, emissions, and ozone formation.

Therefore, more intricate methods that addressed the known variability in ozone concentrations due to atmospheric and meteorological variability were also investigated. A complete literature review of these methods was performed including telephone discussions with selected scientists. The review identified several promising techniques for assessing trends in air quality. These techniques were discussed in detail in Section 2 which included a summary of the pros, cons, and data requirements of each technique. This discussion and summary should assist the ARB, Districts, and others in selecting and performing future analyses.

Several adjustment methods were selected from the review. The selected methods adjusted the observed ozone concentrations using different approaches to evaluate the true trend in ozone over time when ozone variability due to atmospheric and meteorological variability was minimized. The selected adjustment methods also featured minimal data needs, which allowed them to be applied to selected PAMS sites even with limited data. The adjustment methods smoothed, fit, or filtered the ozone concentration measurements and in general, clarified the observed trends using the requisite statistical indicators. In some cases, the adjustment methods were not sensitive or robust enough to fully discern trends even when some variability was removed.

11.1.2 Conclusions

When all the selected sites are considered, a statewide improvement in ozone air quality was observed from the late 1980s to the late 1990s. For example, there was a clear reduction in the number of exceedance days that experienced ozone concentrations in excess of the California Ozone Standard at nearly all of the selected PAMS or PAMS-like sites. Each air basin also experienced a reduction in the number of cumulative exposure hours to elevated ozone concentrations. Variability in the ozone data due to analysis uncertainty and atmospheric and meteorological variability was found to obscure trends. Meteorological adjustment techniques provided further evidence that the reductions in observed ozone were not solely due to meteorological changes.

Trends in ozone precursors were also investigated, including morning NMHC and NO_x trends. While the relationship between benzene reductions in RFG implementation dates, and declines in benzene concentrations in ambient air are clear (e.g., Hammond, 1996; Main et al., 1998), the relationship between ambient concentrations of ozone precursors and ozone concentrations is less well defined. In this project, the precursor trends were compared to ozone trends in order to provide another "piece of the puzzle". Because the trends were unclear, additional research and analysis are required, including photochemical modeling. Additional research will clarify the linkage between the ozone changes and precursor trends.

A number of statistical methods were used to determine indicators of ozone trends. Overall, the following conclusions may be drawn:

- Several indicators are robust indicators of ozone trends and reveal decreasing ozone trends at the studied sites, including the number of exceedances, the top three exceedance concentrations, and cumulative population-weighted exposure hours.
- Several indicators are influenced by the variability in the ozone concentrations and do not reveal clear trends, including the average exceedance concentration, the 3-yr running average exceedance concentration, the second highest exceedance concentration, the ratio of early morning precursor concentrations, and the ratio of exceedance days to days with temperatures above 90°F.

Methods were also used to adjust the indicators of ozone trends. Overall, the following conclusions may be drawn:

- The Cox and Chu probabilistic technique consistently clarified ozone trends, but the uncertainty of the method could not be evaluated in this project.
- The Rao and Zurbenko Kolmogorov-Zurbenko filter technique consistently clarifies ozone trends but did not account for large portions of the variability in seasonal ozone concentrations at these sites. Again, the uncertainty of the method could not be evaluated in this project.

- The ARB RECRATE technique produced indicators that were still influenced by the variability in the ozone concentrations and did not consistently clarify trends, including EPDC and native variability limits on EPDC and average exceedance concentrations.

Trends in Sacramento

- The consensus is that *ozone concentrations decreased* at the PAMS Del Paso Manor and Folsom sites from 1987 to 1997. The number and severity (highest concentration) of the exceedances of the 1-hr ozone standards decreased as well. While many of the statistical indicators produced inconclusive results, the adjustment analyses showed clear downward trends.
- Ozone data were only available at Elk Grove from 1993 through 1997. The ozone trend from 1993 to 1997 appeared upward at this site. However, ozone concentrations followed the year-to-year ozone trends at Del Paso Manor. A longer ozone record is needed to assess the long-term trend at this site.
- While total morning NMHC concentrations did not show a strong trend between 1994 and 1997, the NMHC composition (i.e., individual hydrocarbon concentrations) changed significantly over this time period. For example, evidence suggests that the implementation of RFG in early 1996 resulted in a *42 percent decrease in ambient benzene concentrations* at Del Paso Manor between 1994 and 1997.
- The ambient morning NO_x concentrations at Del Paso Manor showed a slight, but not statistically significant, increase from 1994 to 1997. As a result, the morning NMHC/NO_x ratio decreased slightly between 1995 and 1996 although the change was within measurement variability.
- It is encouraging to note that despite high population growth and increases in vehicle miles traveled (VMT) in the Sacramento Valley air basin since 1990 (California Air Resources Board, 1999), the meteorologically adjusted ozone trends suggest that ozone concentrations at the PAMS sites appear to be nearing compliance with the 1-hr NAAQS. As stated by ARB (California Air Resources Board, 1999), it is likely that further controls on precursor emissions will be needed in order to reach compliance with the State and national ambient air quality standards.

Trends in Bakersfield and Fresno

- The consensus for the Arvin site is that ozone concentrations *declined only slightly* between 1989 and 1997 with little change in the 1990s. Similarly, between 1994 and 1997, there was *little change* in ozone concentrations at the Golden State Avenue site in Bakersfield. However, the number and severity of the exceedances of the 1-hr ozone standards at both sites decreased.
- The consensus for the Parlier site is that ozone concentrations have *declined only slightly* between 1987 and 1997 with little change in the 1990s. Similarly, from

1990 to 1997, the ozone concentrations above, and number of exceedances of, the 1-hr Ozone NAAQS showed a very slight decline at the Fresno 1st Street site. However, there was little change in ozone concentrations at the Clovis site from 1991 to 1997. The Parlier site was one of the few sites for which the Rao and Zurbenko meteorological adjustment results were inconclusive.

- While total morning NMHC concentrations at the Bakersfield area sites did not show a strong trend between 1994 and 1997, individual hydrocarbon concentrations changed significantly. For example, evidence suggests that the implementation of RFG in early 1996 resulted in a *61 percent decrease in ambient benzene* concentrations at the Bakersfield Golden State Avenue site between 1994 and 1997. Likewise, while total morning NMHC concentrations did not show a strong trend at Parlier (1995 to 1997), Clovis (1994 to 1997), or Fresno 1st Street (1990 to 1997), evidence suggests that the implementation of RFG in early 1996 resulted in a *35 to 53 percent decrease in ambient benzene* concentrations at the three sites.
- The ambient morning NO_x concentrations and morning NMHC/NO_x ratios at the Golden State Avenue and Parlier sites showed little change from 1994 to 1997.
- The lack of significant changes in ozone concentrations in the SJV, at a time when ozone concentrations are declining elsewhere in California, suggests a more complex relationship between geography, meteorology, and emissions with ozone concentrations in the SJV.

Trends in Los Angeles

- The consensus is that there was a *substantial decline* in the average ozone exceedance concentration and the number of exceedances of the 1-hr ozone standards per year from 1987 to 1997 at the Los Angeles North Main Street site. While some of the statistical indicators produced inconclusive results, most of the statistical and adjustment analyses showed clear downward trends.
- While total morning NMHC concentrations showed no significant change during the sampling period, the NMHC composition (i.e., individual hydrocarbon concentrations) changed significantly. Evidence suggests that the implementation of RFG in early 1995 and again in 1996 resulted in a *60 percent decrease in ambient benzene concentrations* at the Los Angeles North Main Street site between 1990 and 1997.
- The ambient morning NO_x concentrations at the Los Angeles North Main Street site did not change significantly between 1991 and 1997. The morning NMHC/NO_x ratio decreased slightly since 1991, but the change was within measurement variability.
- Despite high population growth and increases in VMT in the South Coast Air Basin since 1990 (California Air Resources Board, 1999), aggressive emission control programs have apparently helped to continue to reduce ozone concentrations.

Trends in San Diego

- The consensus is that there was a *substantial decline* in the average ozone exceedance concentration and the number of exceedances per year from 1989 to 1997 at the San Diego 12th Street site. While some of the statistical indicators produced inconclusive results, most of the statistical and adjustment analyses showed clear downward trends.
- While total morning NMHC concentrations showed no significant change during the sampling period, evidence suggests that the implementation of RFG in early 1995 and again in 1996 resulted in a *48 percent decrease in ambient benzene concentrations* at the San Diego 12th Street between 1992 and 1997. The ambient morning NO_x concentrations and NMHC/NO_x ratios at the San Diego 12th Street site did not change significantly between 1992 and 1997.
- Despite high population growth and increases in VMT in the San Diego Air Basin since 1990 (California Air Resources Board, 1999), most analyses (including the meteorologically adjusted ozone trends) suggest that ozone concentrations at the 12th Street site are declining.

Trends in Ventura

- The consensus is that *ozone concentrations decreased* at the PAMS Simi Valley, El Rio, and Emma Wood sites from 1987 to 1997. The number and severity of the exceedances of the 1-hr ozone standards has decreased as well. While a few of the statistical indicators produced inconclusive results, most analyses showed clear downward trends. Adjustment analyses were not performed at this site due to data limitations.
- Total morning NMHC concentrations showed a slight, but not statistically significant, increase at El Rio between 1995 and 1997. The Simi Valley NMHC concentrations did not exhibit a change during this time period; however, a 33 *percent decrease in ambient benzene concentrations* was observed at Simi Valley between 1995 and 1997. Surprisingly, El Rio NMHC data did not show a change in benzene concentrations during this time.
- The ambient morning NO_x concentrations at El Rio did not show a significant change between 1995 and 1997. The morning NMHC/NO_x ratios increased slightly although the change was within measurement variability.

11.2 RECOMMENDATIONS

The successes and difficulties in interpreting the trends in selected indicators (with and without adjustment) led to the development of the following list of recommendations.

Ozone Research and Analysis Recommendations

- Currently, adjustment techniques are either not publicly available or are difficult to use. The EPA and ARB should consider developing user-friendly versions of adjustment techniques, including ARB RECRATE, Cox and Chu probabilistic fit, and the Kolmogorov-Zurbenko filter.
- Documentation for the adjustment techniques is often difficult to understand. The EPA and ARB should consider developing improved documentation for the use of, and basis behind, the adjustment techniques, including ARB RECRATE, Cox and Chu probabilistic fit, and Kolmogorov-Zurbenko filter.
- Both the Cox and Chu probabilistic fit and Kolmogorov-Zurbenko filter adjustment techniques appear promising for use in California. However, the seasonal meteorological effects on ozone were not well accounted for using only surface temperature at San Diego. Other meteorological parameters that are critical to ozone formation and variability in ozone formation in California need to be incorporated into the techniques and reapplied to the California sites. CART analyses could be used to identify important meteorological parameters to include in the Kolmogorov-Zurbenko filter method.
- The ARB should consider updating the RECRATE model to determine EPDC and native variability using 1-hr average ozone concentrations in ppb units; RECRATE is currently written for pphm data.
- This work focused on the 1-hr ozone exceedance issue. The EPA and ARB should evaluate the need to update the ARB RECRATE, Cox and Chu probabilistic fit, and Kolmogorov-Zurbenko filter adjustment techniques to accommodate 8-hr average ozone concentrations.
- All sites studied still exceed the 1-hr Ozone NAAQS and California Ozone Standard. However, the ARB should consider investigating statistical (requisite) and adjustment (intricate) trends in 8-hour ozone concentrations using the techniques investigated in this work.

VOC Research and Analysis Recommendations

- The Kolmogorov-Zurbenko filter adjustment model appears promising in filtering out seasonal and long-term meteorological affects in ozone concentration data. The ARB and EPA should consider investigating the application of this filtering method to continuous NMHC measurements to elucidate temporal trends in the measurements. This would require at least three years of continuous hourly NMHC measurements.
- The focus of the VOC investigations in this work was on the trends in morning concentrations and composition because morning data best represent the fresh emissions. An initial investigation of afternoon n-butane concentrations and weight fractions at the Los Angeles North Main Street site showed possible declines that could

be attributed to RFG implementation (i.e., lower RVP). The EPA and ARB should consider investigating trends in the afternoon NMHC measurements, including more volatile hydrocarbons associated with evaporative emissions. Adjustment techniques may be required to account for the variability due to meteorology and other factors.

- Even though total NMHC concentrations may not necessarily have changed, this work showed that the composition exhibited large changes, particularly with respect to benzene. Since ozone concentrations appear to be declining in many cases, perhaps the total reactivity of the NMHC is also declining. The EPA and ARB should consider investigating trends in early morning NMHC reactivity. For an effective analysis, however, the relatively large portion of the NMHC that is currently unidentified may need to be reduced (see Main et al., 1999).
- This work focused on the NMHC/NO_x ratios based on the PAMS 3-hr canister data. Additional analyses should be performed using NMHC/NO_x ratios based on the continuous NMHC data. For example, these data are more suitable to a study of day-of-week issues.

Monitoring Recommendations

- Meteorological adjustment techniques studied in this project require, at a minimum, daily maximum surface temperature measurements. In many cases, these data were incomplete or otherwise unavailable although adequate surrogates for temperature (i.e., data from nearby sites) were often available. The ARB and Districts should continue to make data completeness a priority for surface temperature measurements. At a minimum, the availability of surrogate temperature measurements should be assured.
- For both the Cox and Chu and Rao and Zurbenko adjustment methods, meteorological parameters in addition to surface temperature may be required to better fit the seasonal variations in the data. Possible measurements include temperature at 850 mb (T850), dew point temperature (T_{dp}), wind speed (WS), and wind direction (WD).
- The ARB and Districts should consider obtaining speciated hourly early morning NMHC measurements to enable ozone trends to be evaluated in the context of total NMHC reactivity.

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APPENDIX A

TEMPERATURE MEASUREMENT CORRELATION PLOTS

Temperature measurements were not as complete as the ozone measurements made at the selected sites in the Sacramento, Bakersfield, Fresno, Los Angeles, San Diego, and Ventura areas. In order to investigate the ozone trends in the context of meteorology (where temperature was used as the surrogate for meteorology) using statistical and adjustment techniques, temperature measurements made at nearby NWS stations were used to supplement the existing temperature measurements. Appropriate NWS stations were selected by comparing the available temperature measurements at the air quality sites to temperature measurements made at the NWS stations. Reasonable correlation between the measurements was demonstrated. Appendix A contains the following correlation plots:

- Sacramento – Correlation of temperature measurements at Sacramento Exec and Sacramento Metro Airport.
- Bakersfield – Correlation of temperature measurements at Arvin site and Bakersfield Airport.
- Bakersfield – Correlation of temperature measurements at Golden State site and Bakersfield Airport.
- Fresno – Correlation of temperature measurements at Parlier site and Fresno Air Terminal.
- Fresno – Correlation of temperature measurements at Clovis-Villa site and Fresno Air Terminal.
- Fresno – Correlation of temperature measurements at 1st Street site and Fresno Air Terminal.

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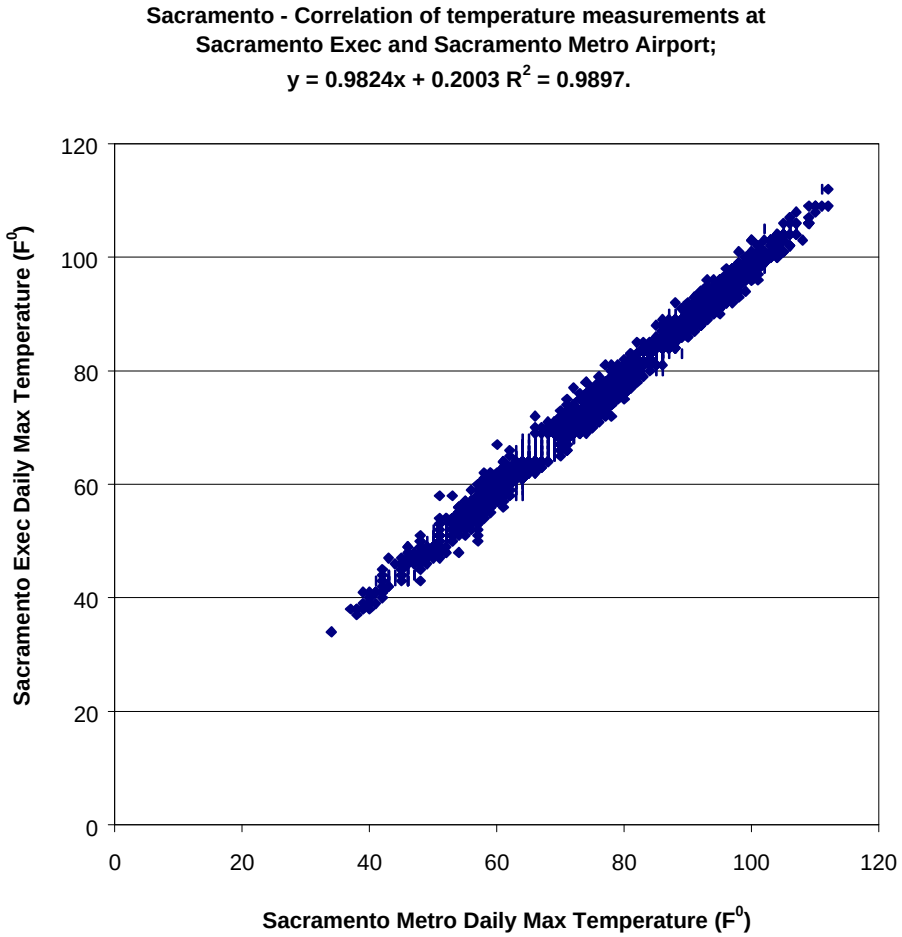
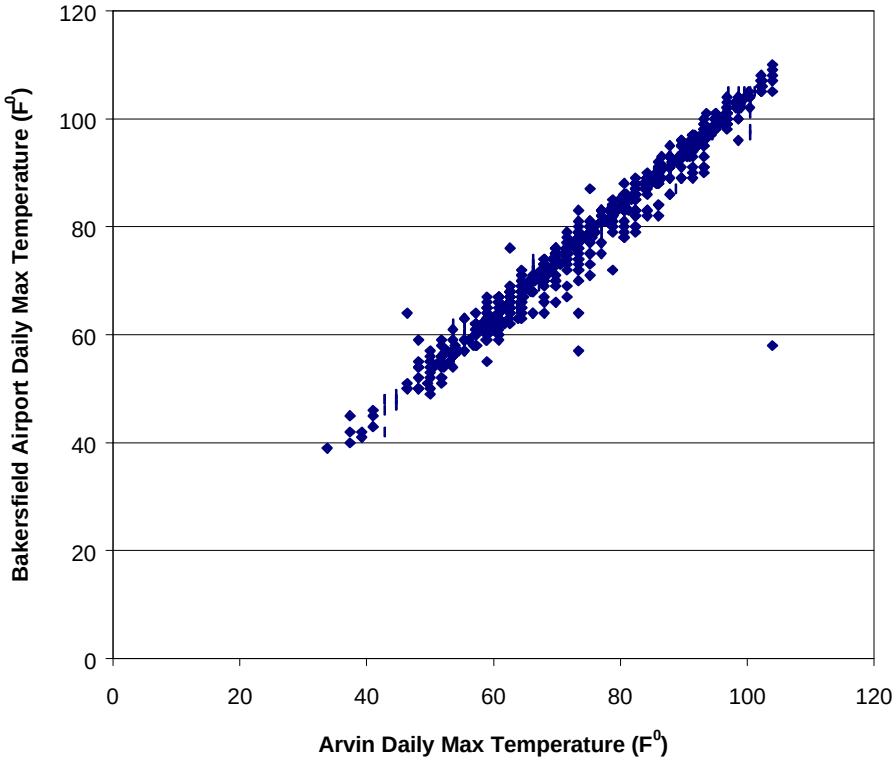
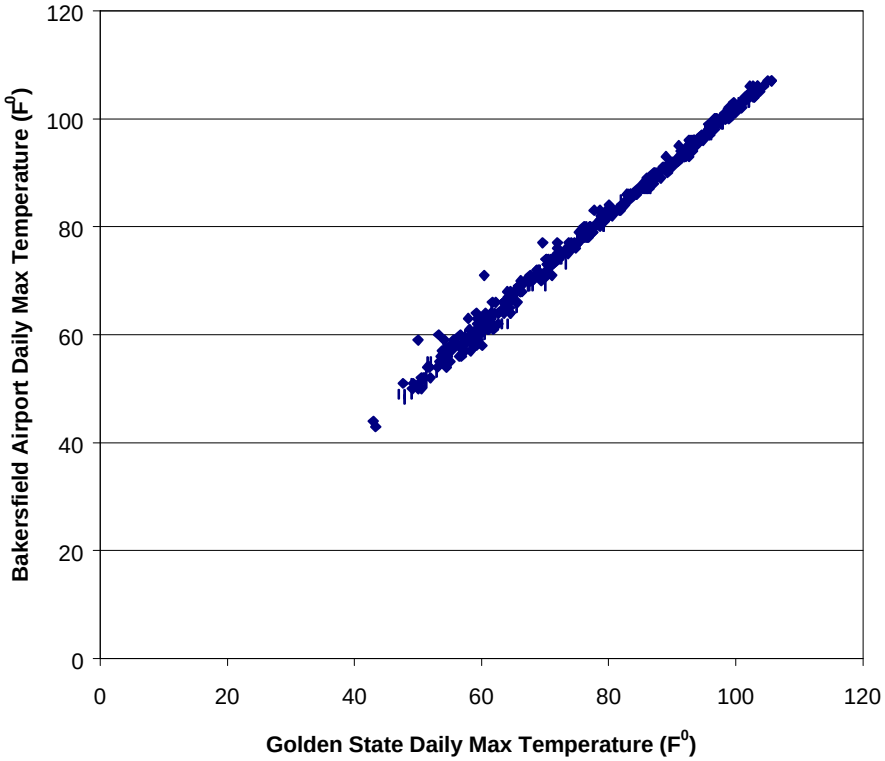

Sacramento - Correlation of temperature measurements at
Sacramento Exec and Sacramento Metro Airport;
y = 0.9824x + 0.2003 R2 = 0.9897.
Sacramento Exec Daily Max Temperature (F0)
Sacramento Metro Daily Max Temperature (F0)
0
20
40
60
80
100
120

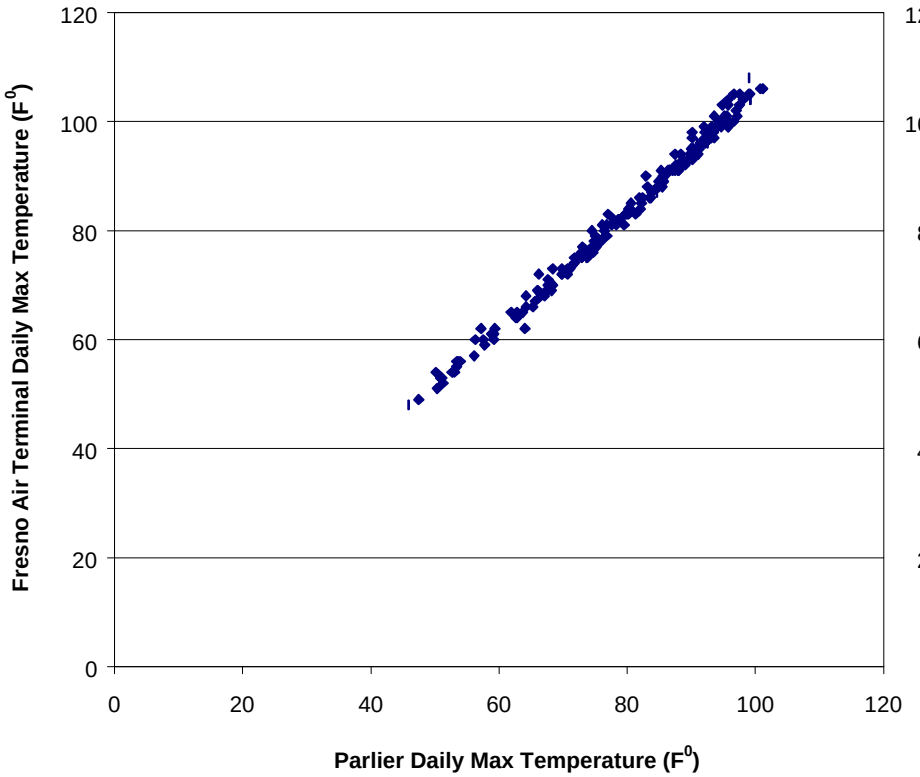
Bakersfield - Correlation of temperature measurements at Arvin Site and Bakersfield Airport; y = 0.9927x + 3.9879 R^2 = 0.9676.



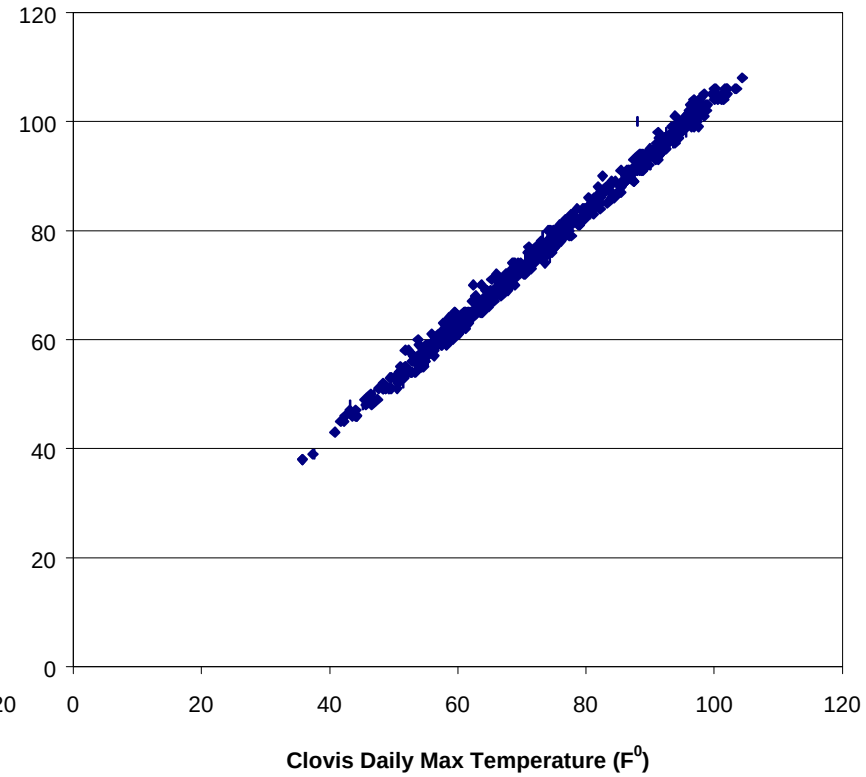
Bakersfield - Correlation of temperature measurements at Golden State Site and Bakersfield Airport; y = 1.006x + 1.5012 R^2 = 0.9945.



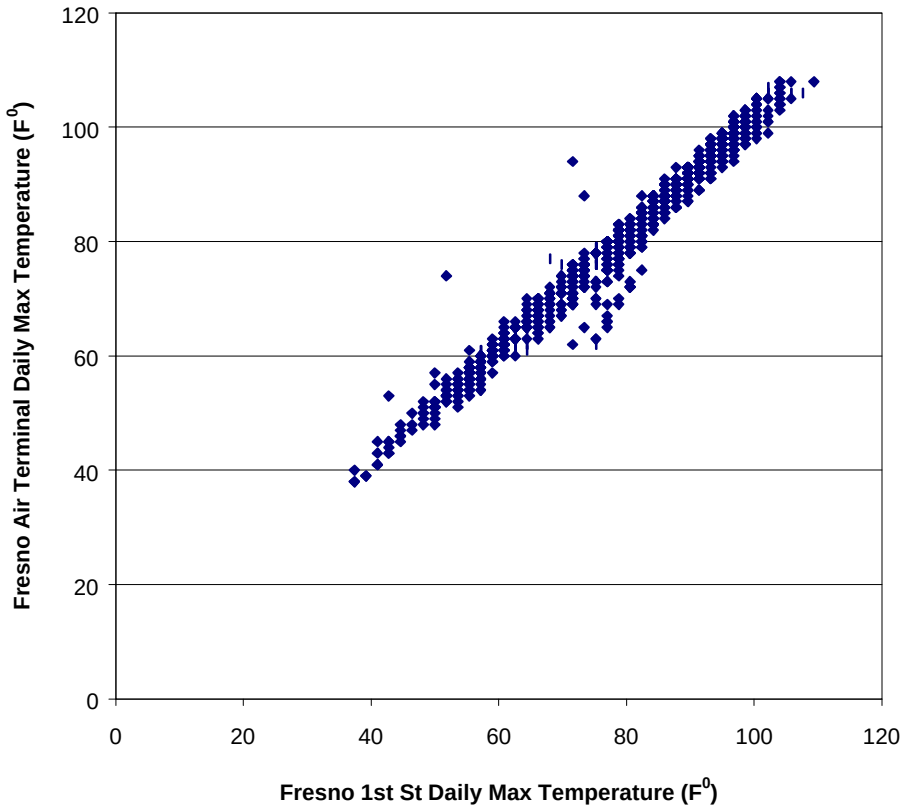
Fresno - Correlation of temperature measurements at Parlier Site and Fresno Airport; y = 1.0853x - 3.2573 R^2 = 0.993.



Fresno - Correlation of temperature measurements at Clovis-Villa Site and Fresno Airport; y = 1.0326x + 0.9516 R^2 = 0.9944.



Fresno - Correlation of temperature measurements at 1st Street Site and Fresno Airport; y = 1.0058x + 0.7471 R^2 = 0.9733.



APPENDIX B

ADDITIONAL SACRAMENTO ANALYSES

Statistical techniques were applied to three Sacramento PAMS sites: Elk Grove-Bruceville (PAMS Type 1 site), Del Paso Manor (PAMS Type 2 site), and Folsom (PAMS Type 3 site). The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS that occurred at the Del Paso Manor site were detailed in Section 4 of the report. The following figures are presented in this Appendix and parallel the analyses of ozone trends performed for the Del Paso Manor site and the 1-hr Ozone NAAQS that were presented in Section 4:

- Exceedances of the California Ozone Standard with analysis uncertainty.
- Del Paso Manor - Total number of exceedances of the California Ozone Standard.
- Del Paso Manor - Identification of the highest exceedance concentrations of the California Ozone Standard.
- Del Paso Manor - Number and ratio of the number of the exceedance days of the California Ozone Standard by meteorology.
- Del Paso Manor - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentrations.

The following figures are presented in this Appendix and pertain to additional analyses of ozone trends that were performed for the Elk Grove-Bruceville and Folsom sites. The figures for each site are presented separately in the following order:

- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the California Ozone Standard.
- Identification of the highest exceedances of the California Ozone Standard.
- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the 1-hr Ozone NAAQS.
- Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS.

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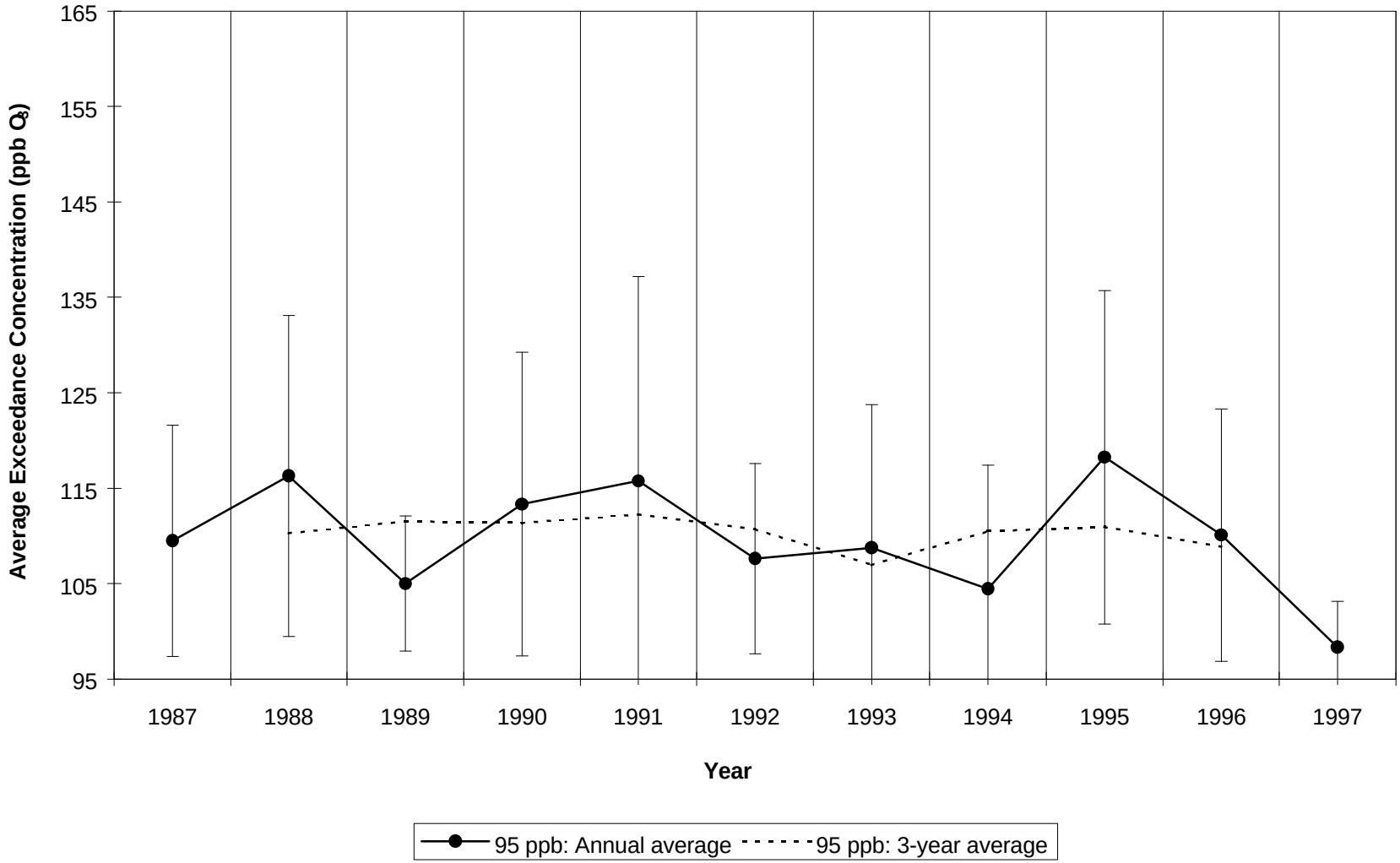
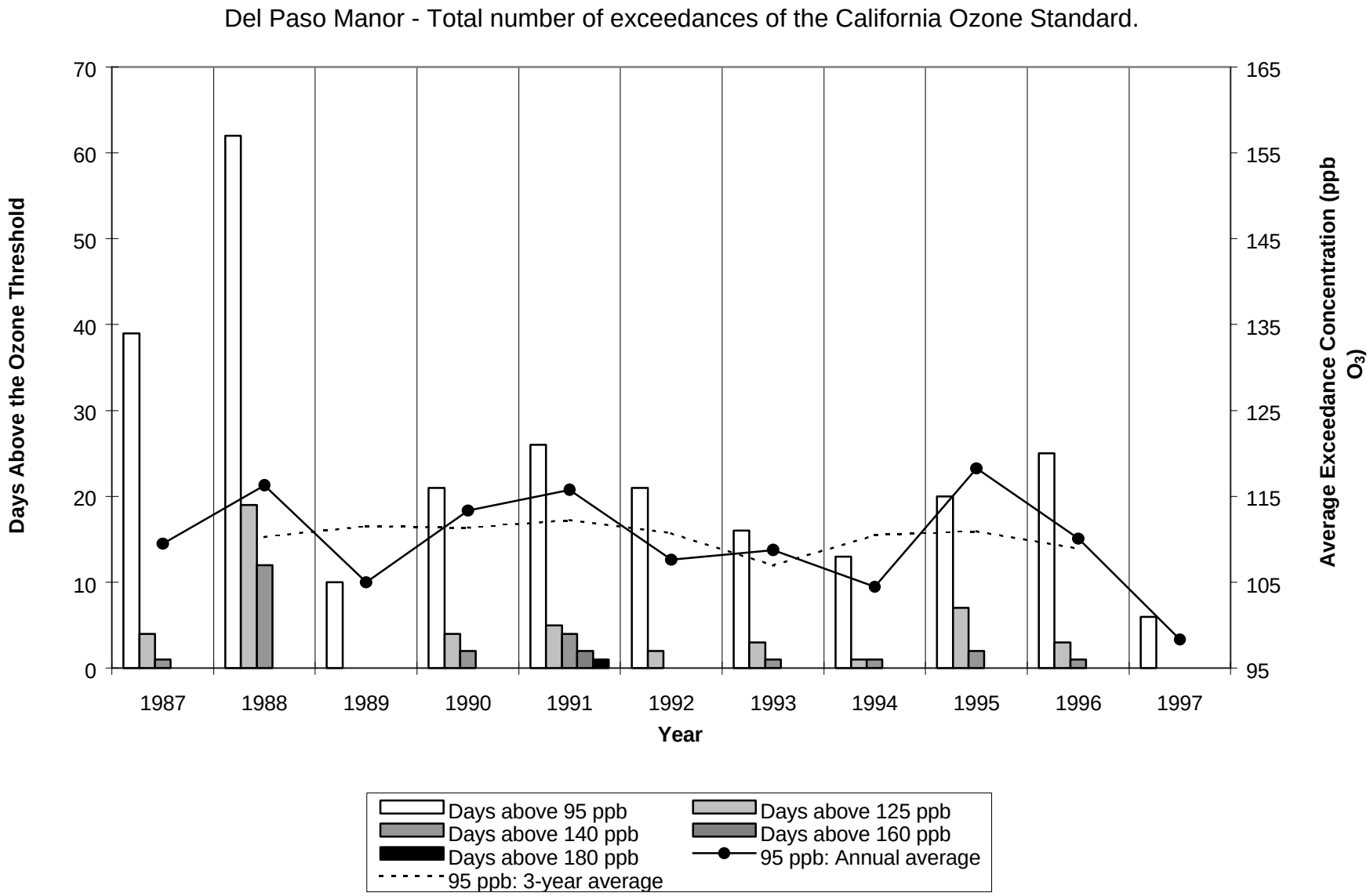
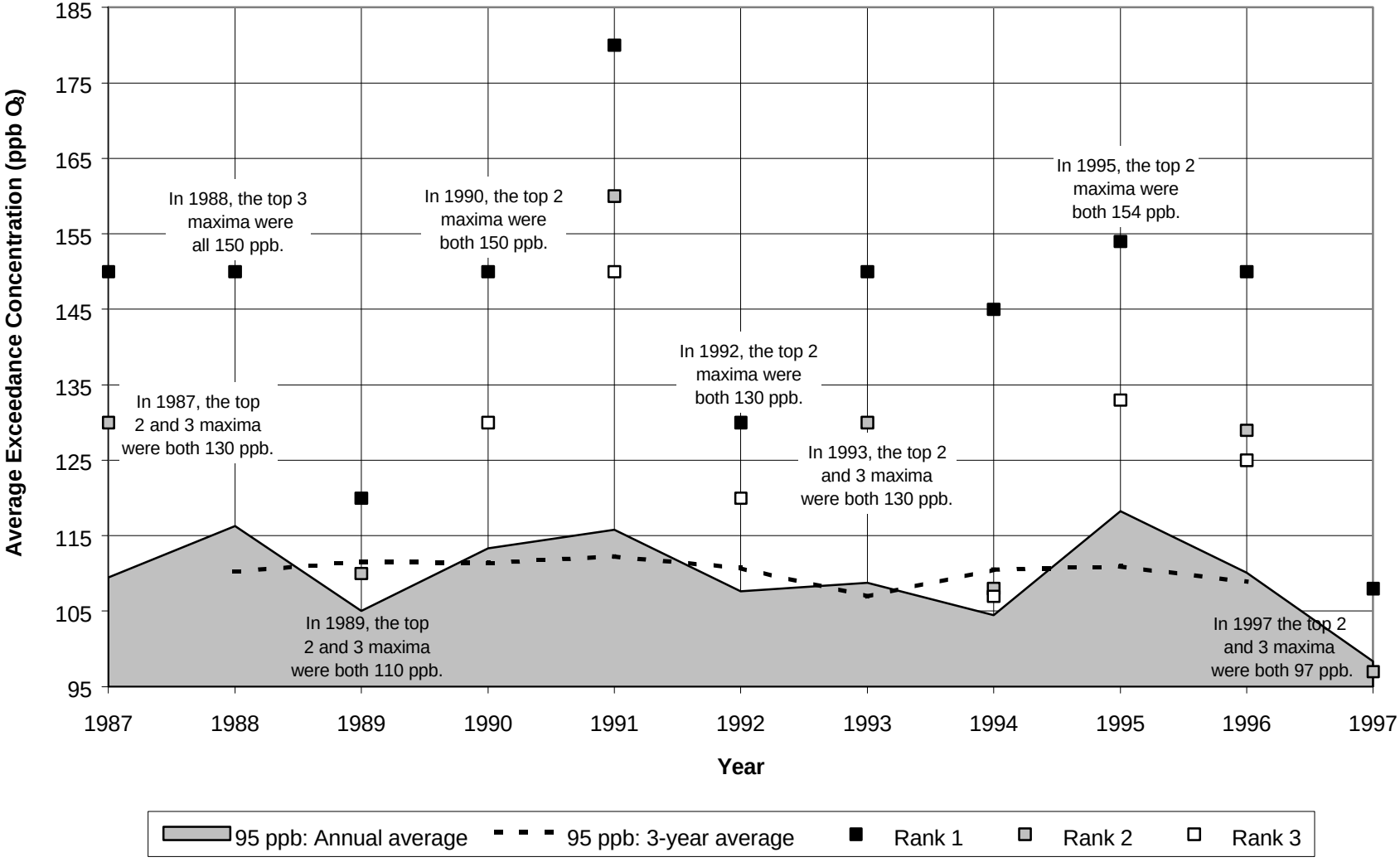
Del Paso Manor - Exceedances of the California Ozone Standard with analysis uncertainty.

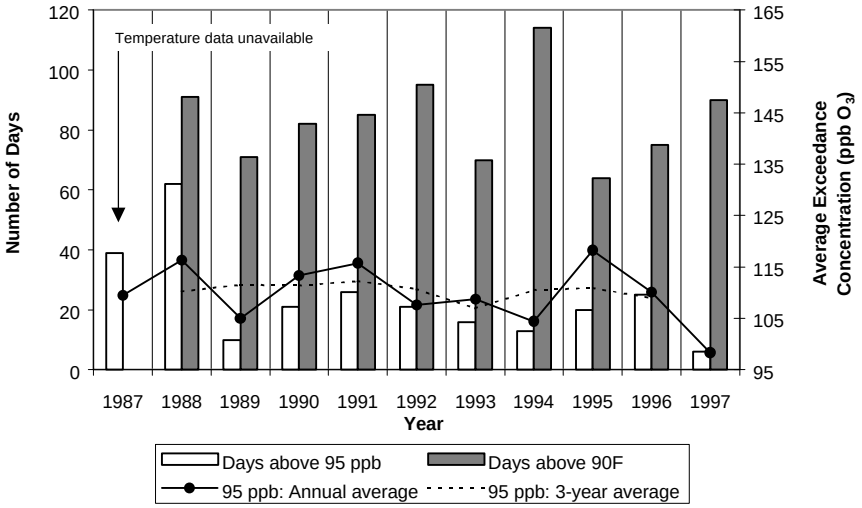


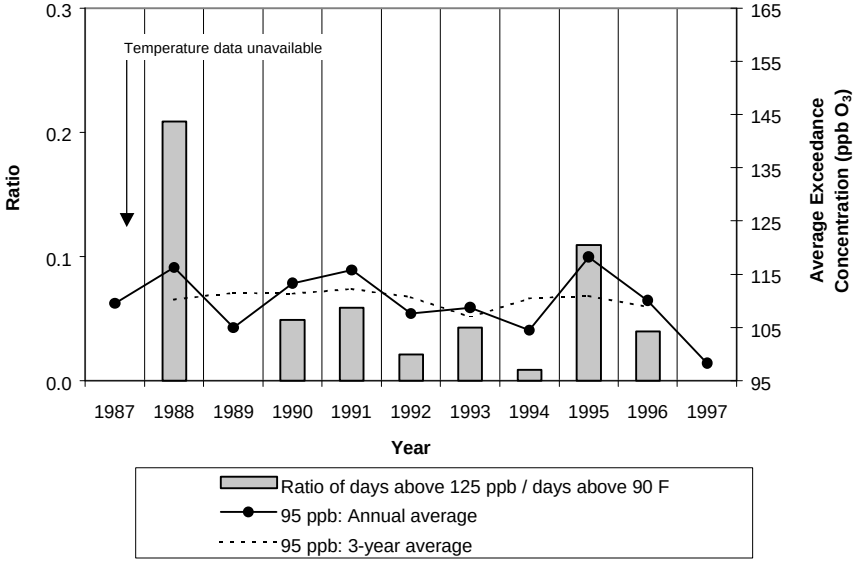

Del Paso Manor - Total number of exceedances of the California Ozone Standard.
Days Above the Ozone Threshold
Average Exceedance Concentration (ppb O_3)
Year
0
10
20
30
40
50
60
70
95
105
115
125
135
145
155
165
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Days above 95 ppb
Days above 125 ppb
Days above 140 ppb
Days above 160 ppb
Days above 180 ppb
95 ppb: Annual average
95 ppb: 3-year average

Del Paso Manor - Identification of the highest exceedance concentrations of the California Ozone Standard.

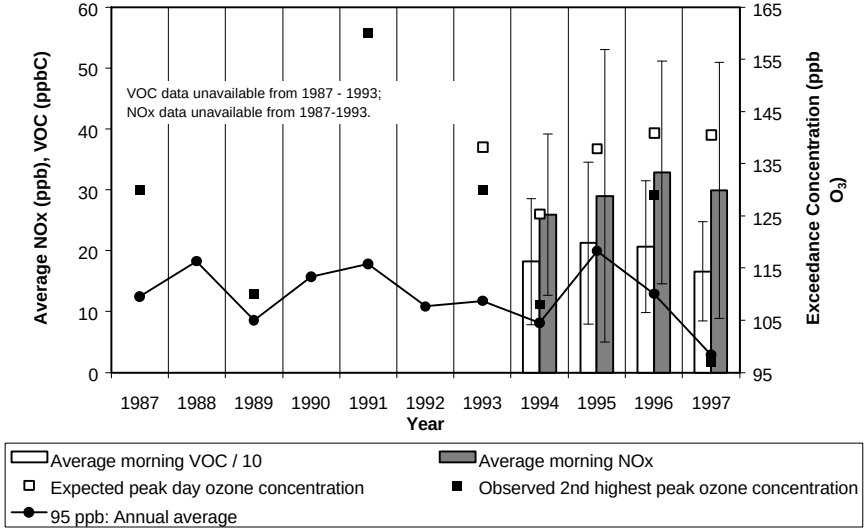


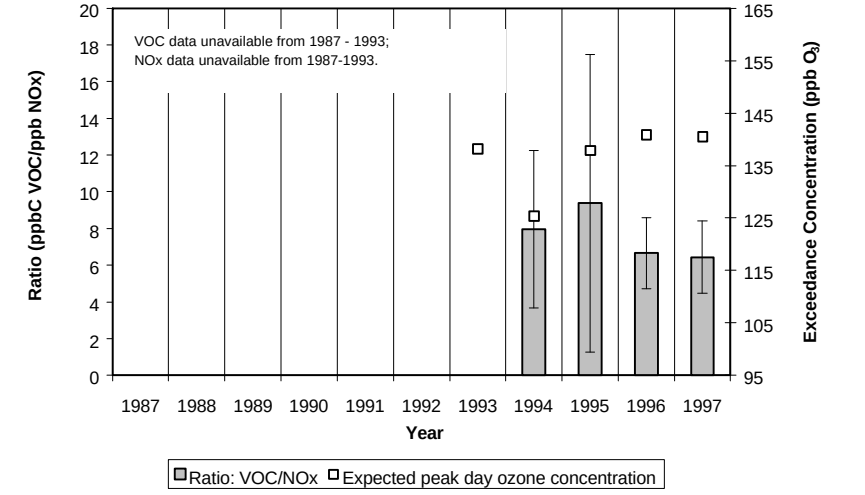
Del Paso Manor - Number and ratio of the number of exceedance days of the California Ozone Standard by meteorology.



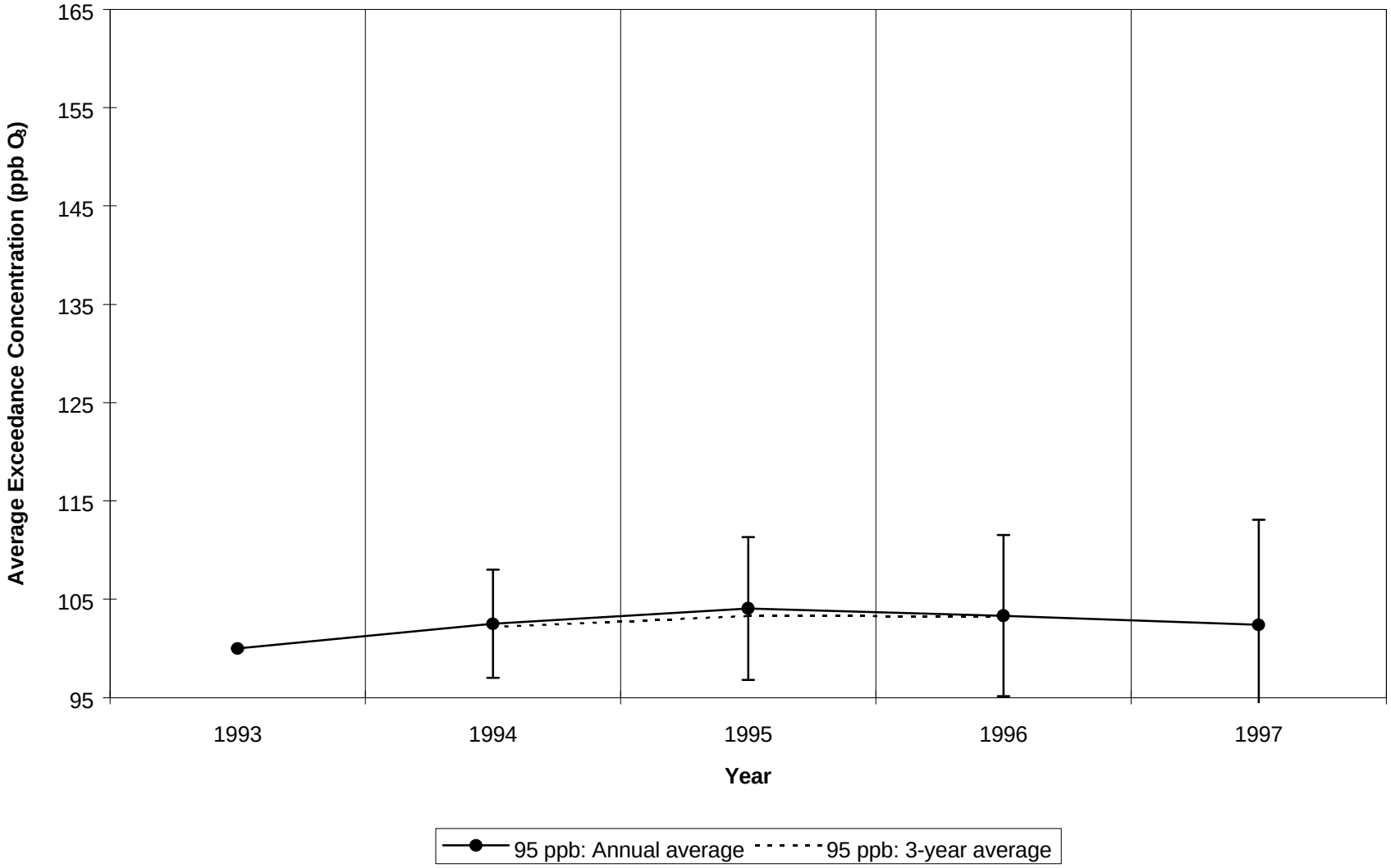


Del Paso Manor - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentrations.

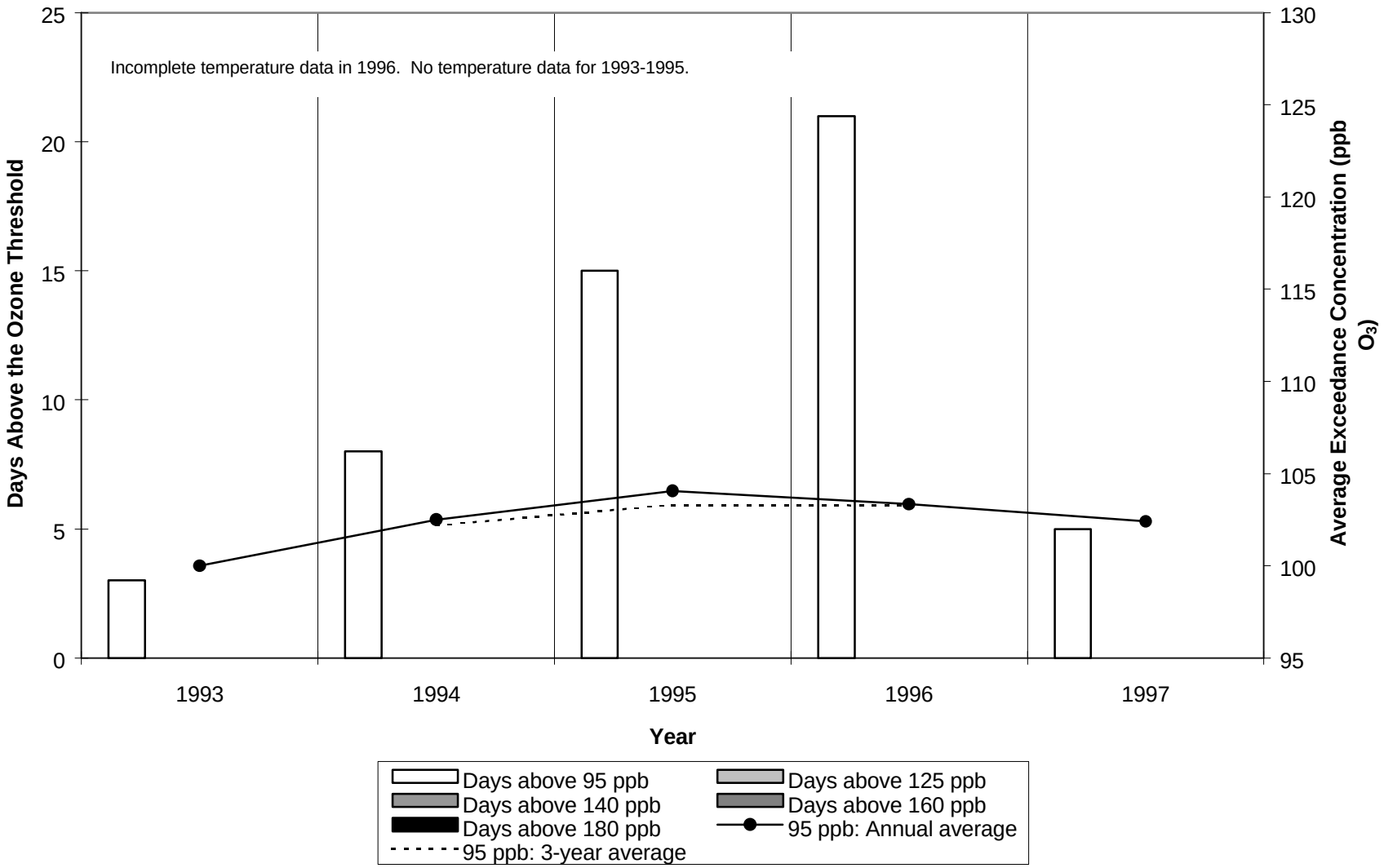




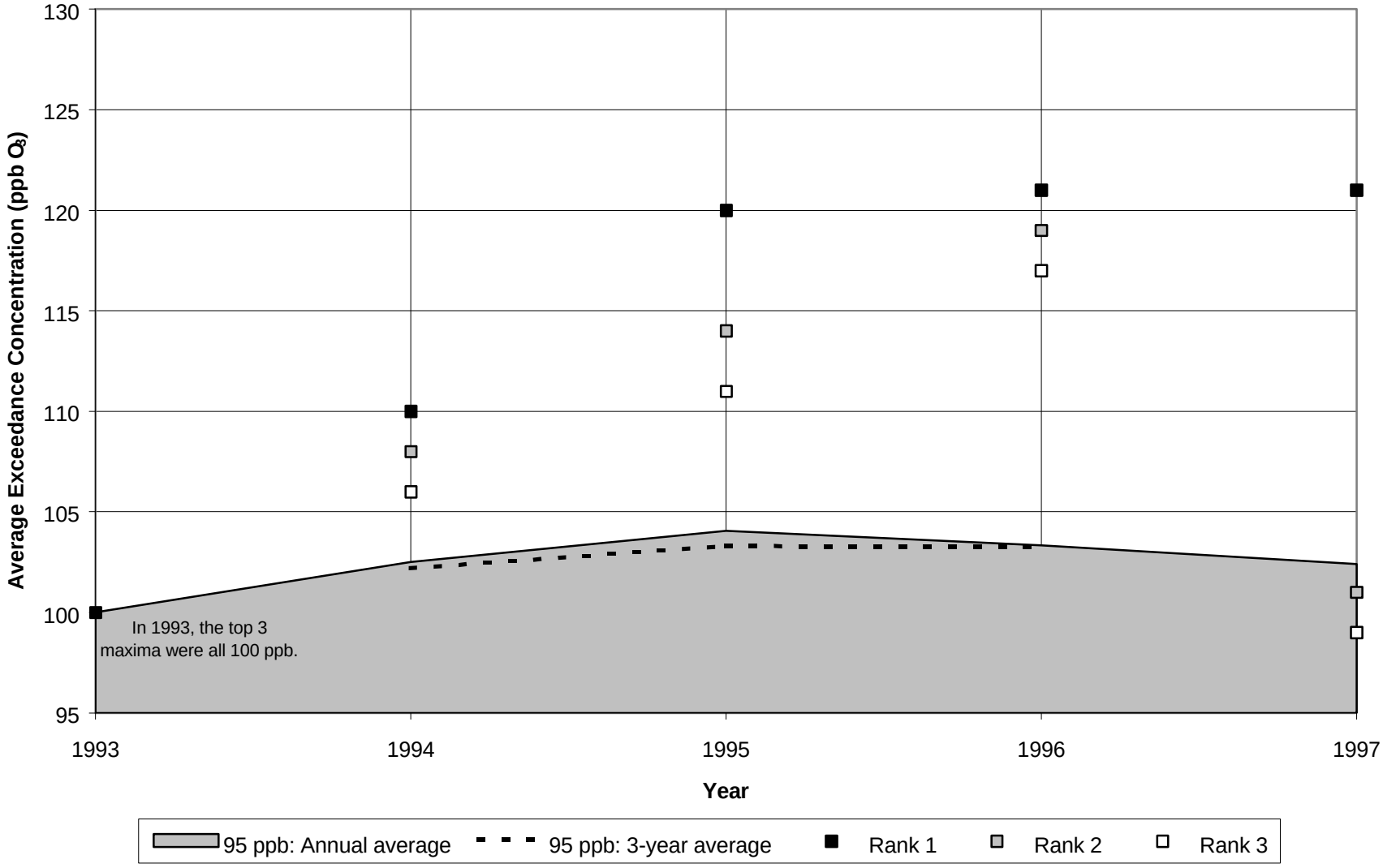
Elk Grove - Exceedances of the California Ozone Standard with analysis uncertainty.



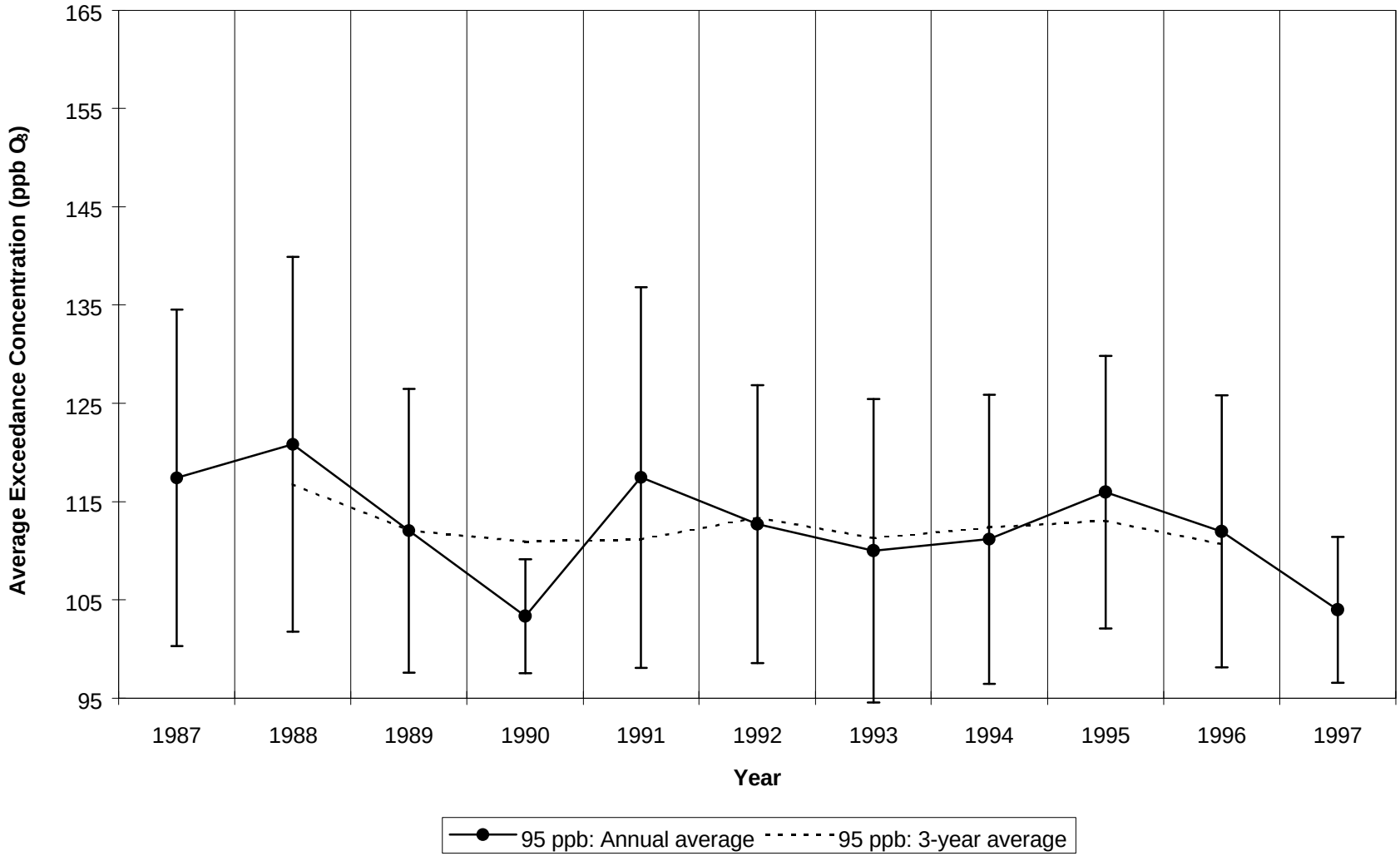
Elk Grove - Total number of exceedances of the California Ozone Standard.



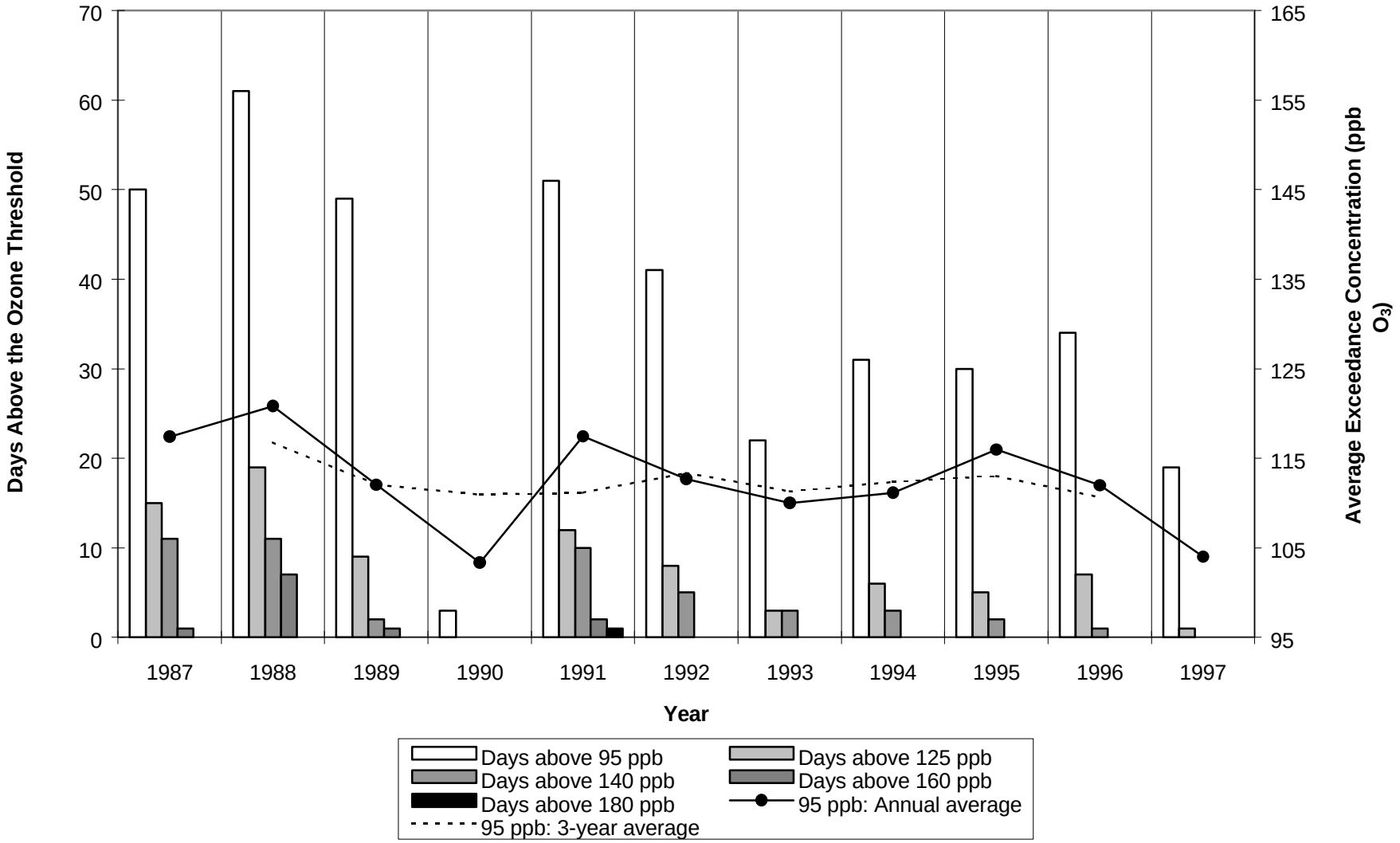
Elk Grove - Identification of the highest exceedance concentrations of the California Ozone Standard.



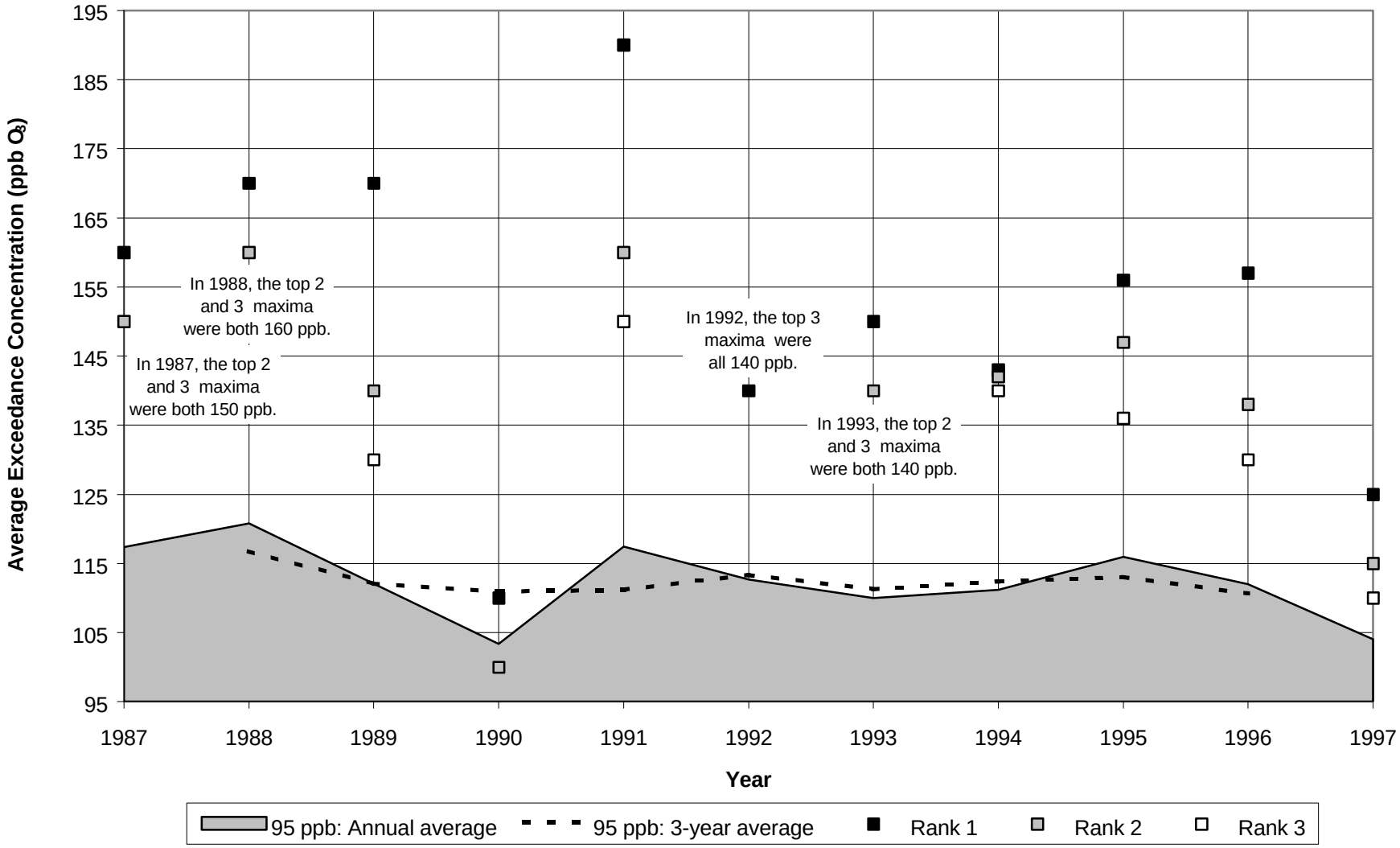
Folsom - Exceedances of the California Ozone Standard with analysis uncertainty.



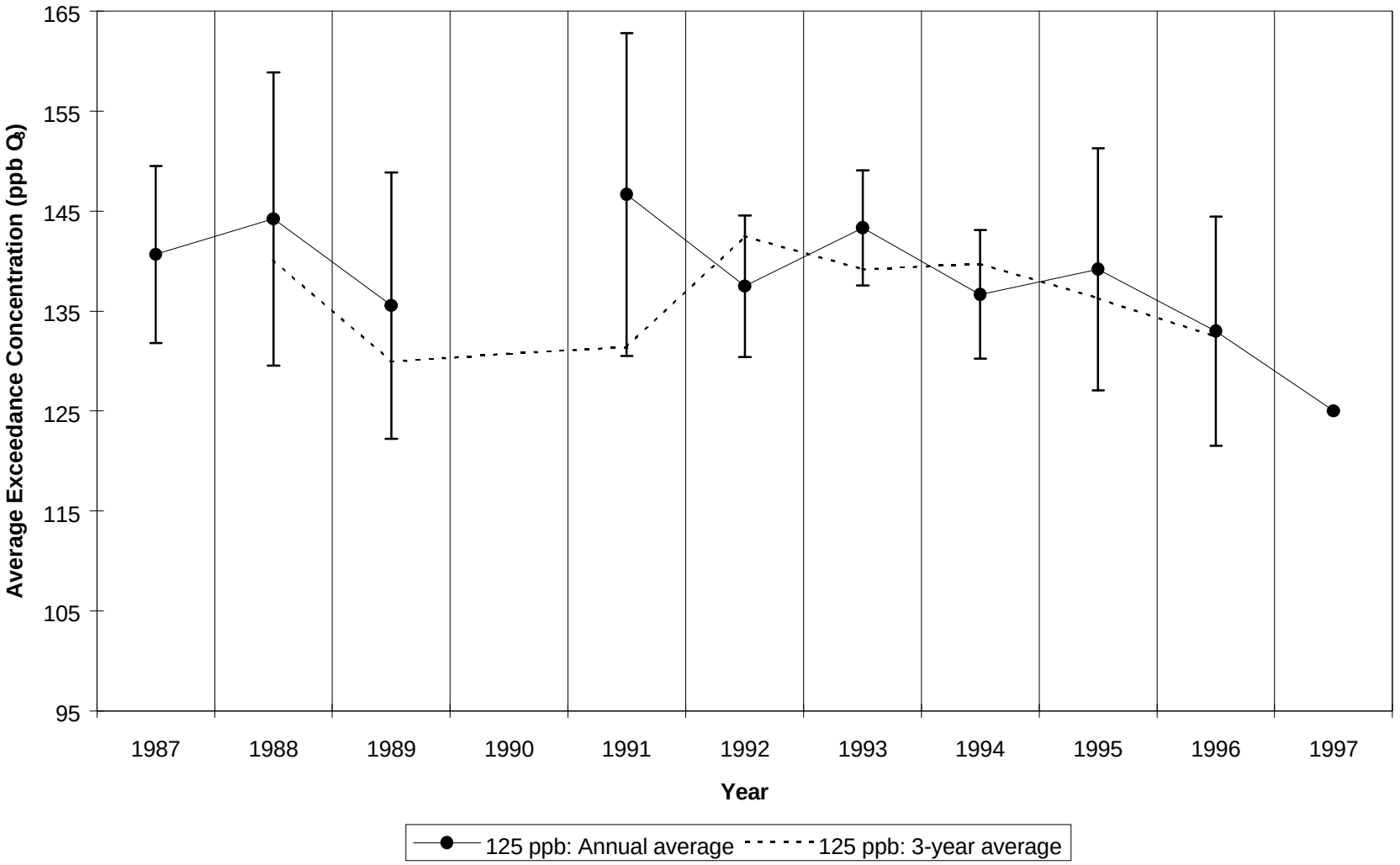
Folsom - Total number of exceedances of the California Ozone Standard.

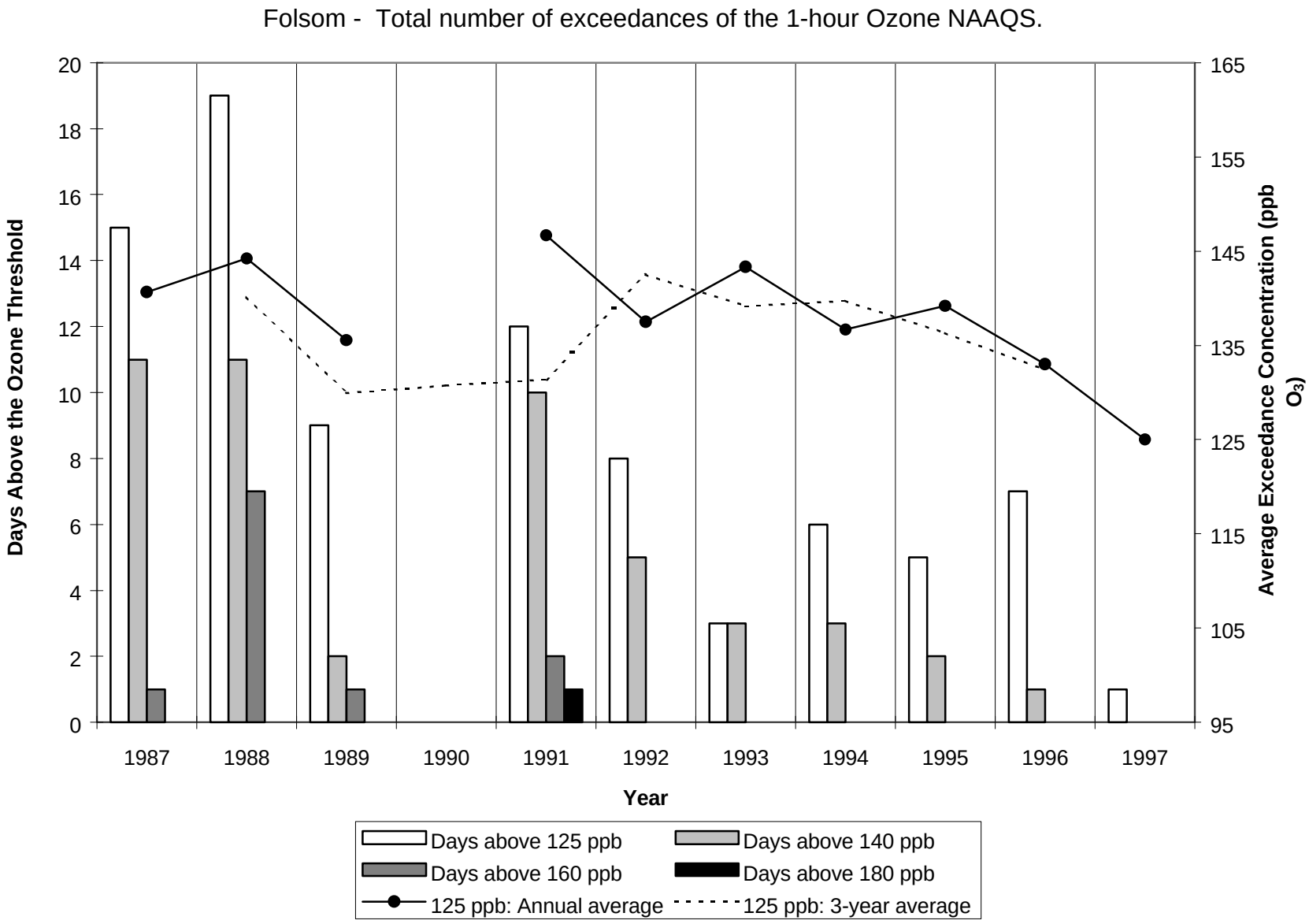


Folsom - Identification of the highest exceedance concentrations of the California Ozone Standard.

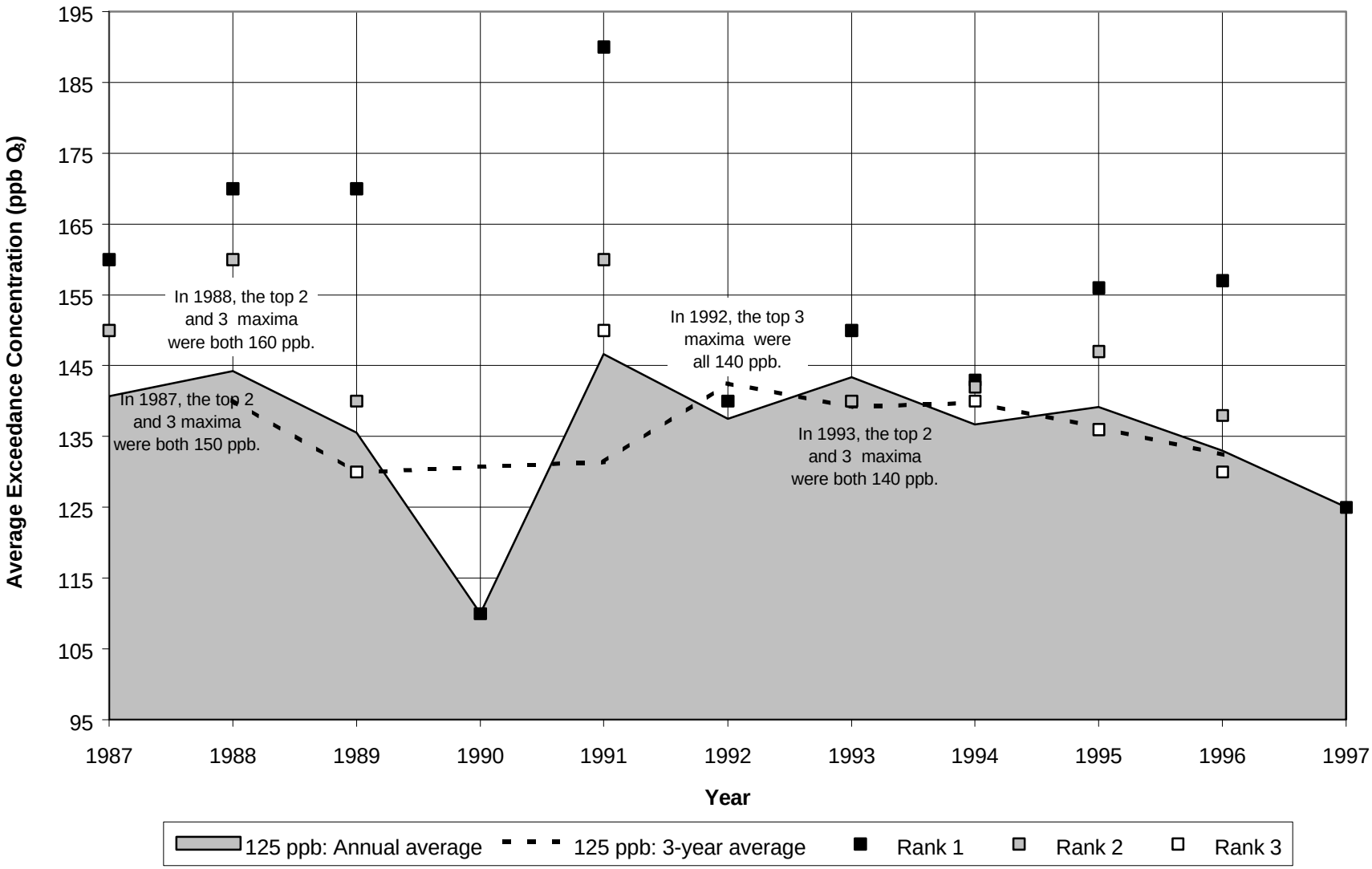


Folsom - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty.




Folsom - Total number of exceedances of the 1-hour Ozone NAAQS.
Days Above the Ozone Threshold
Average Exceedance Concentration (ppb O_3)
Year
0
2
4
6
8
10
12
14
16
18
20
95
105
115
125
135
145
155
165
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Days above 125 ppb
Days above 140 ppb
Days above 160 ppb
Days above 180 ppb
125 ppb: Annual average
125 ppb: 3-year average

Folsom - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.



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APPENDIX C

ADDITIONAL BAKERSFIELD ANALYSES

Statistical techniques were applied to two Bakersfield PAMS sites: Golden State Avenue (PAMS Type 2 site) and Arvin (PAMS Type 1/3 site). The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS that occurred at the Arvin site were detailed in Section 5 of the report. The following figures are presented in this Appendix and parallel the analyses of the Arvin site data and the 1-hr Ozone NAAQS that was presented in Section 5:

- Arvin - Exceedances of the California Ozone Standard with analysis uncertainty.
- Arvin - Total number of exceedances of the California Ozone Standard.
- Arvin - Identification of the highest exceedance concentrations of the California Ozone Standard.
- Arvin - Number and ratio of the number of the exceedance days of the California Ozone Standard by meteorology.
- Golden State Avenue – Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentration.

The following figures are presented in this Appendix and pertain to additional analyses of ozone trends that were performed for the Golden State Avenue site. The figures are presented in the following order:

- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the California Ozone Standard.
- Identification of the highest exceedance concentrations of the California Ozone Standard.
- Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty.
- Total number of exceedances of the 1-hr Ozone NAAQS.
- Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS.

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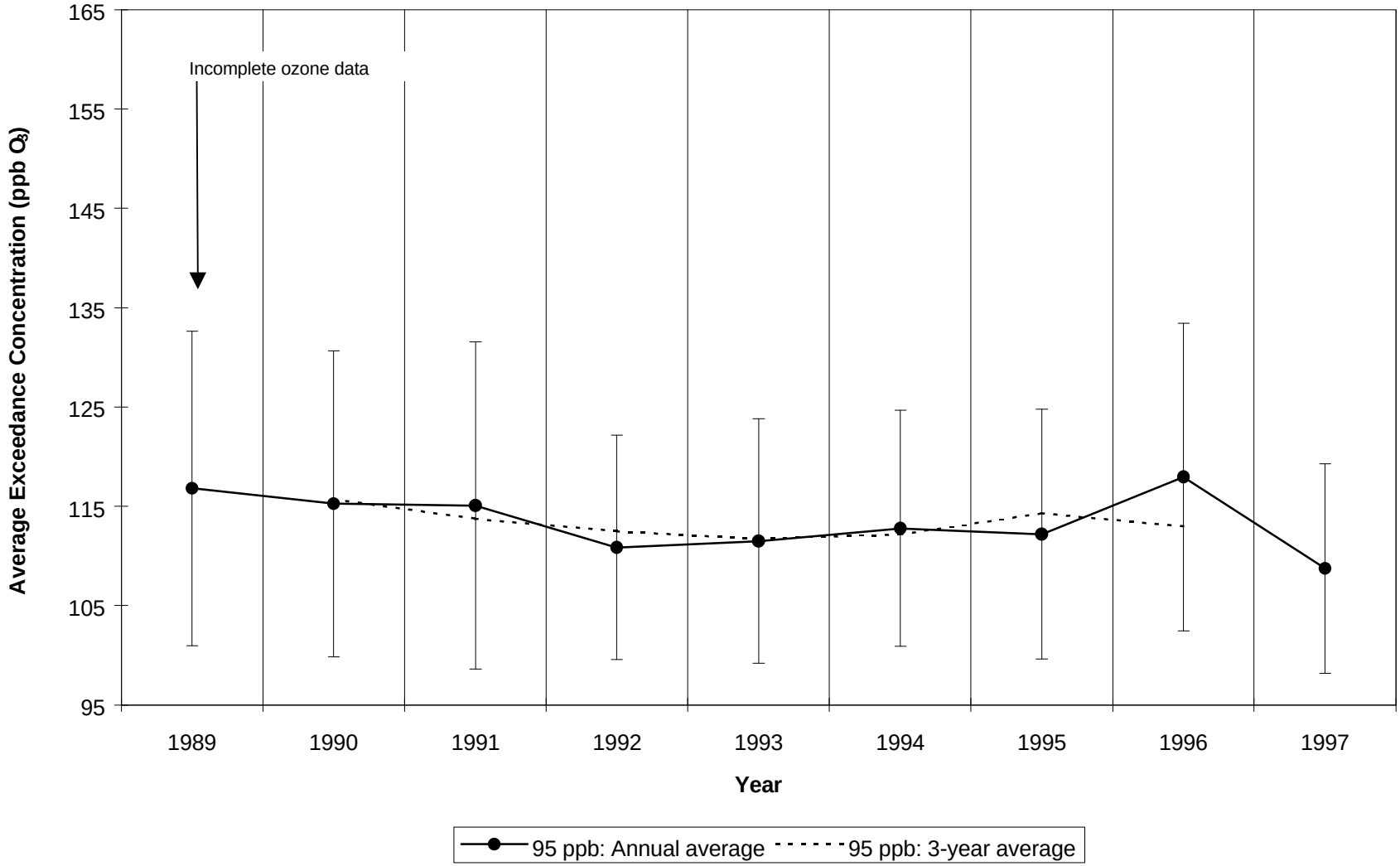
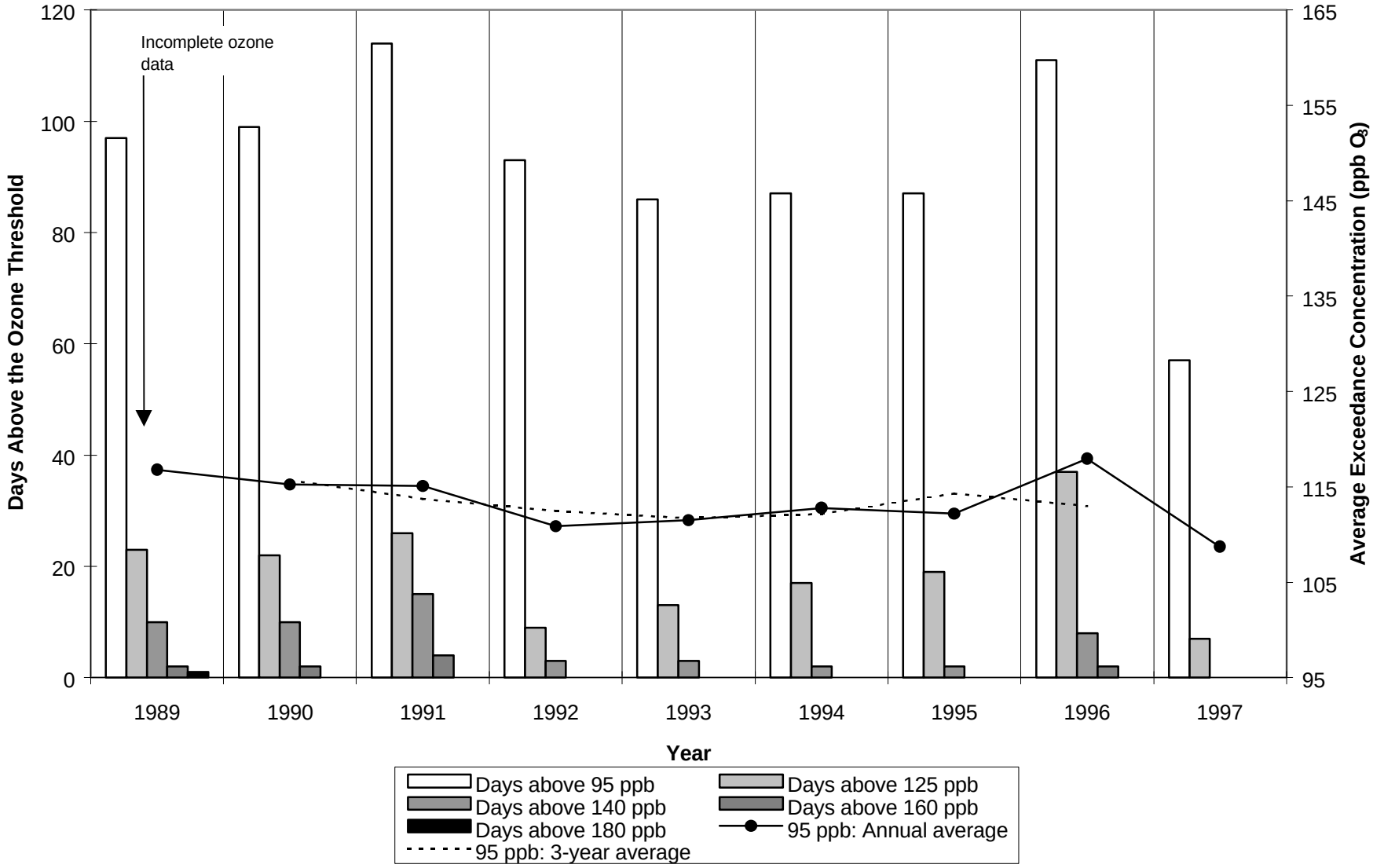
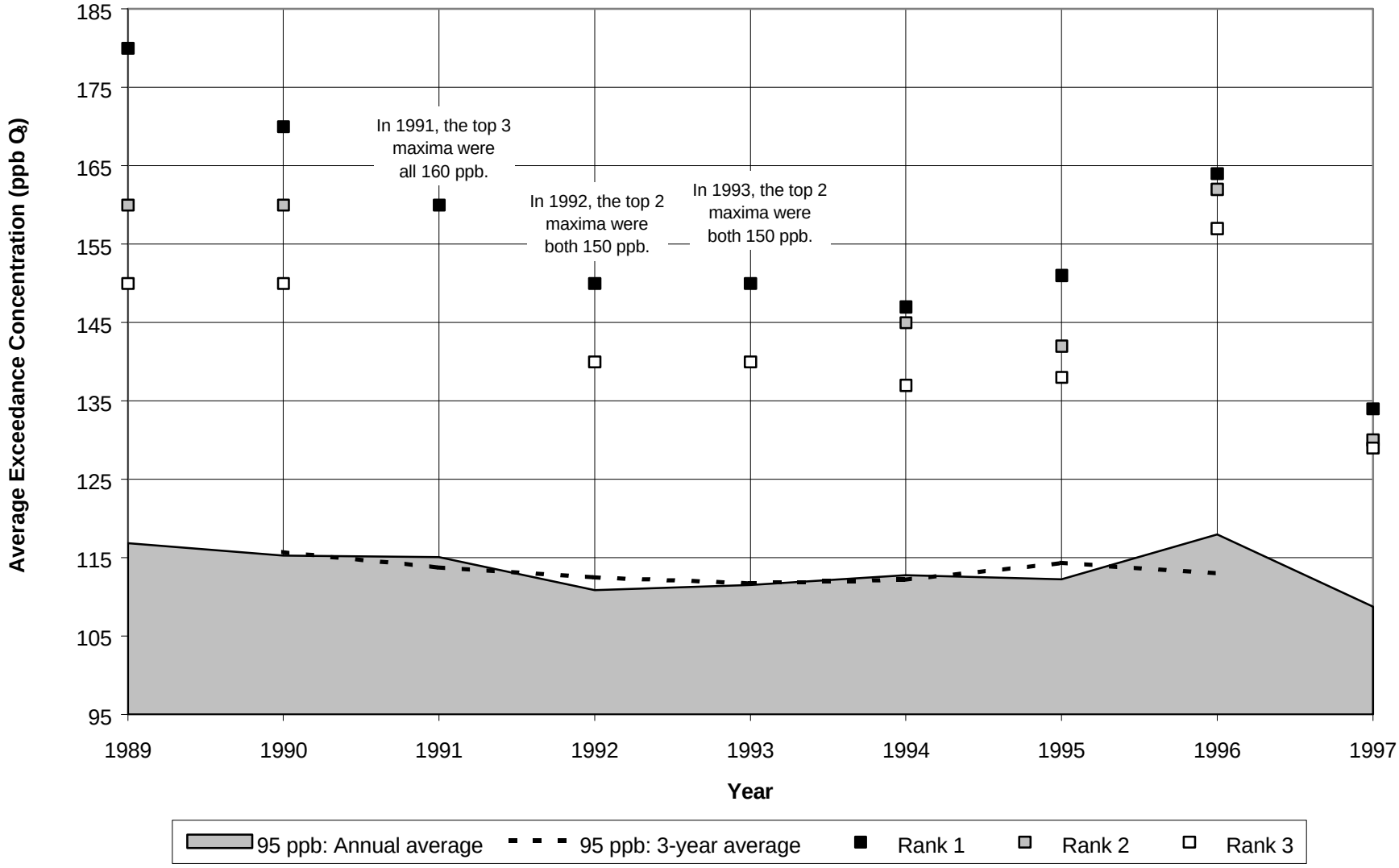
Arvin - Exceedances of the California Ozone Standard with analysis uncertainty.



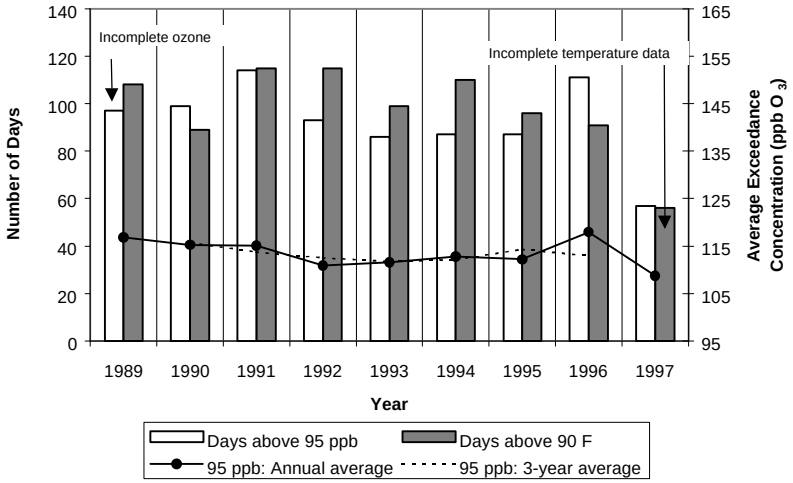
Arvin - Total number of exceedances of the California Ozone Standard.

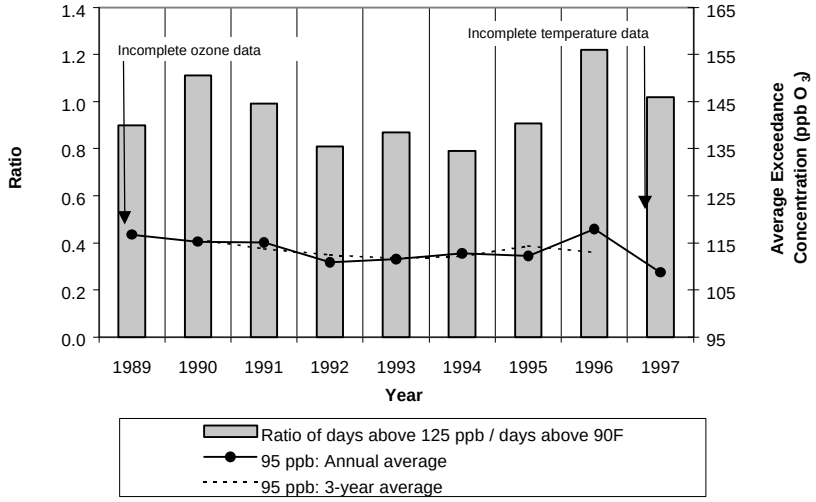


Arvin - Identification of the highest exceedance concentrations of the California Ozone Standard.

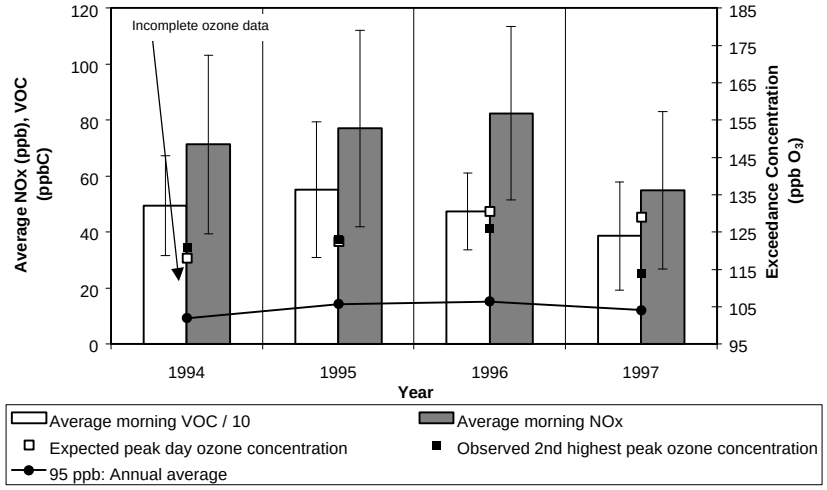


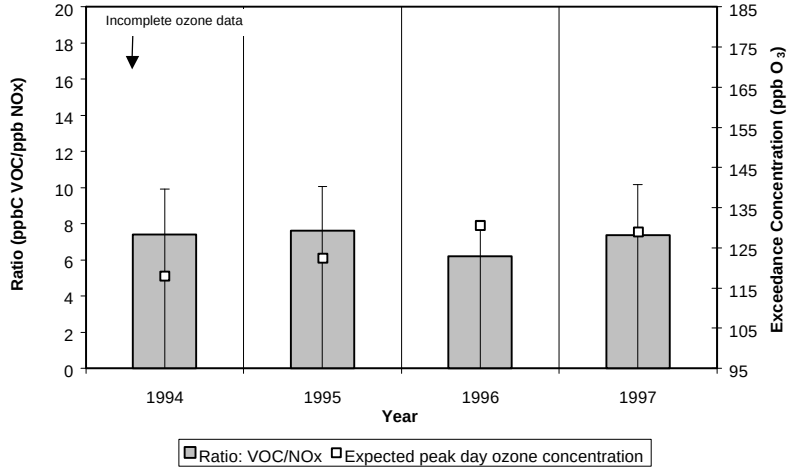
Arvin - Number and fraction of the exceedances of the 1-hour Ozone NAAQS by meteorology.



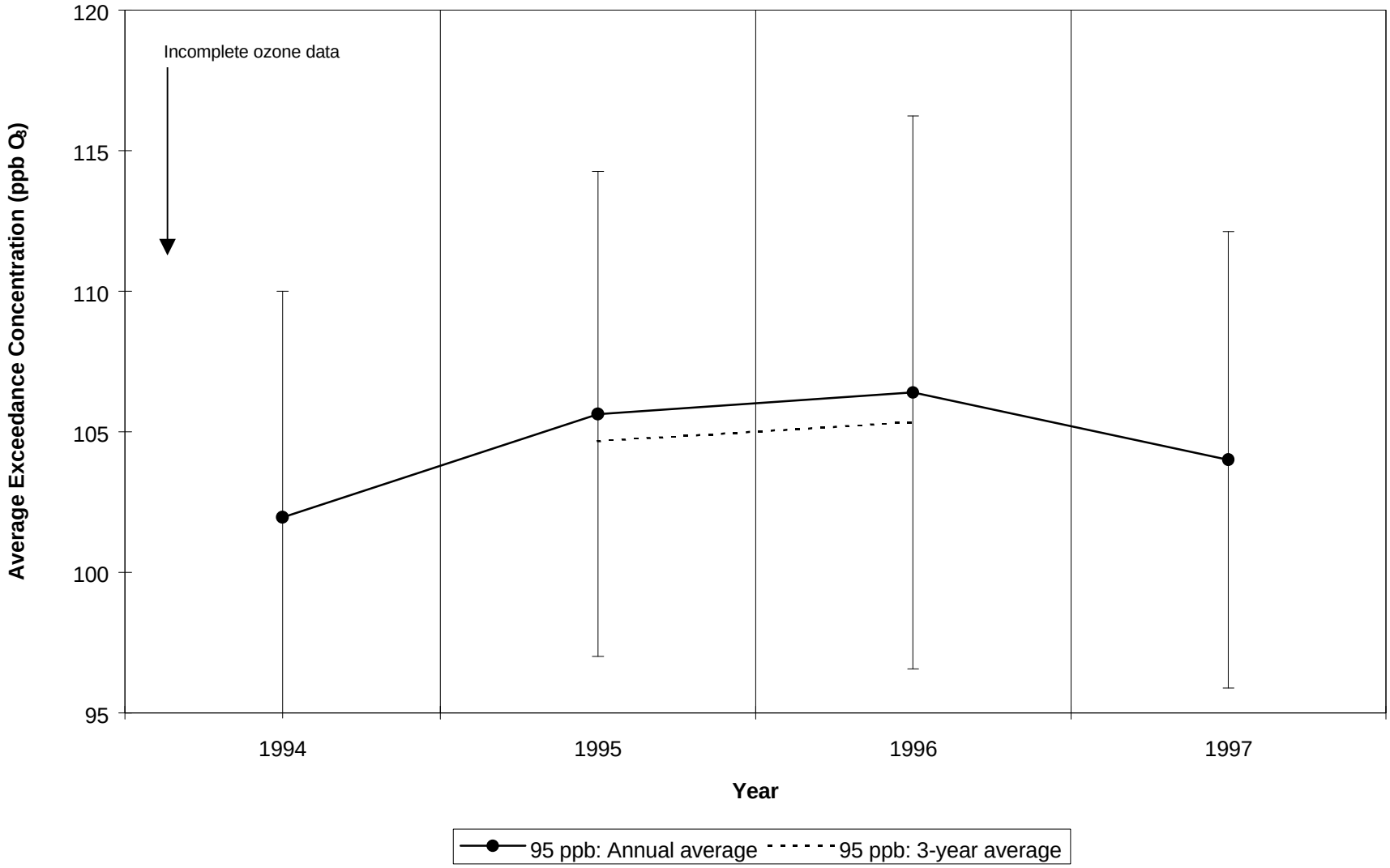


Golden State - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentrations.

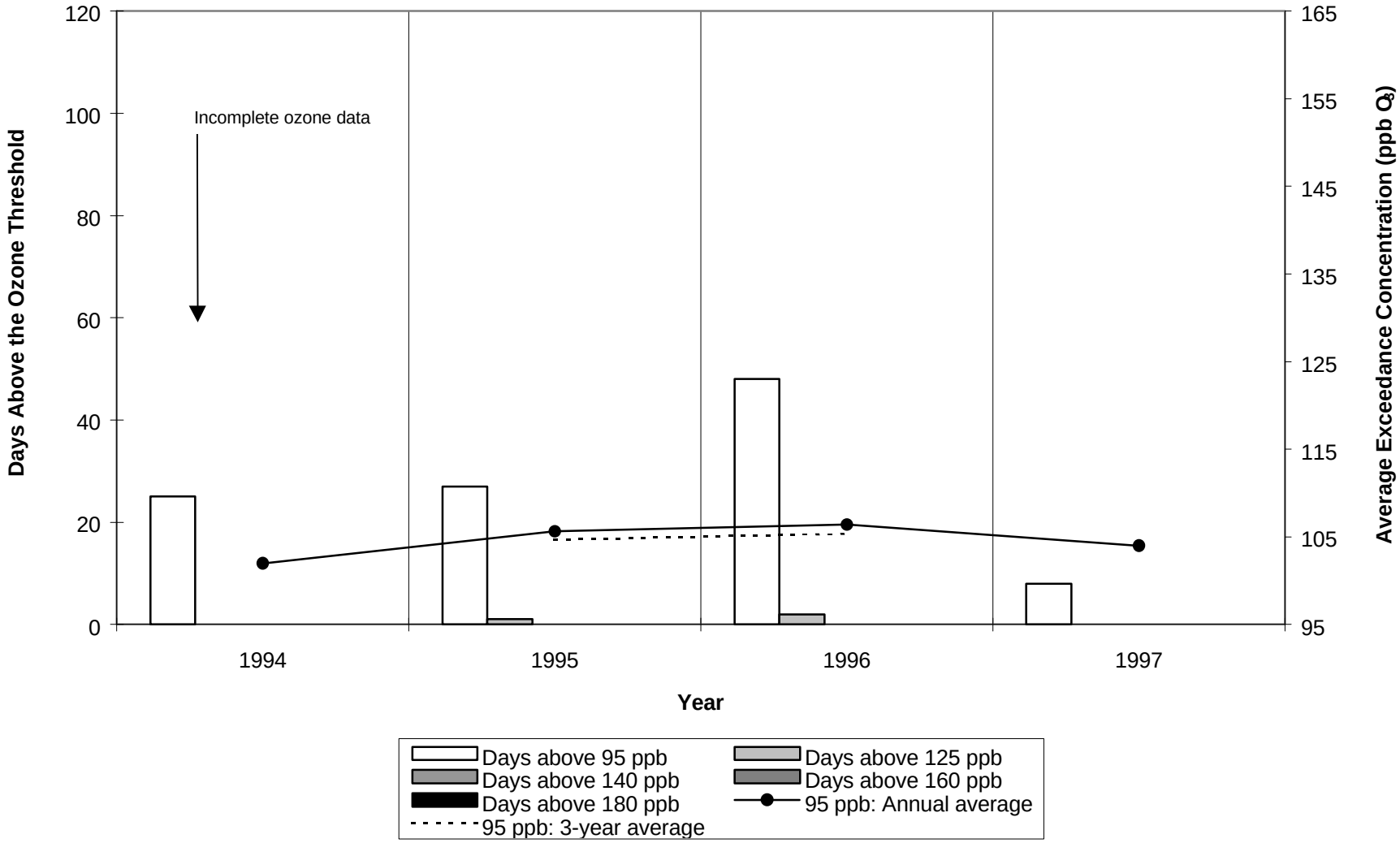




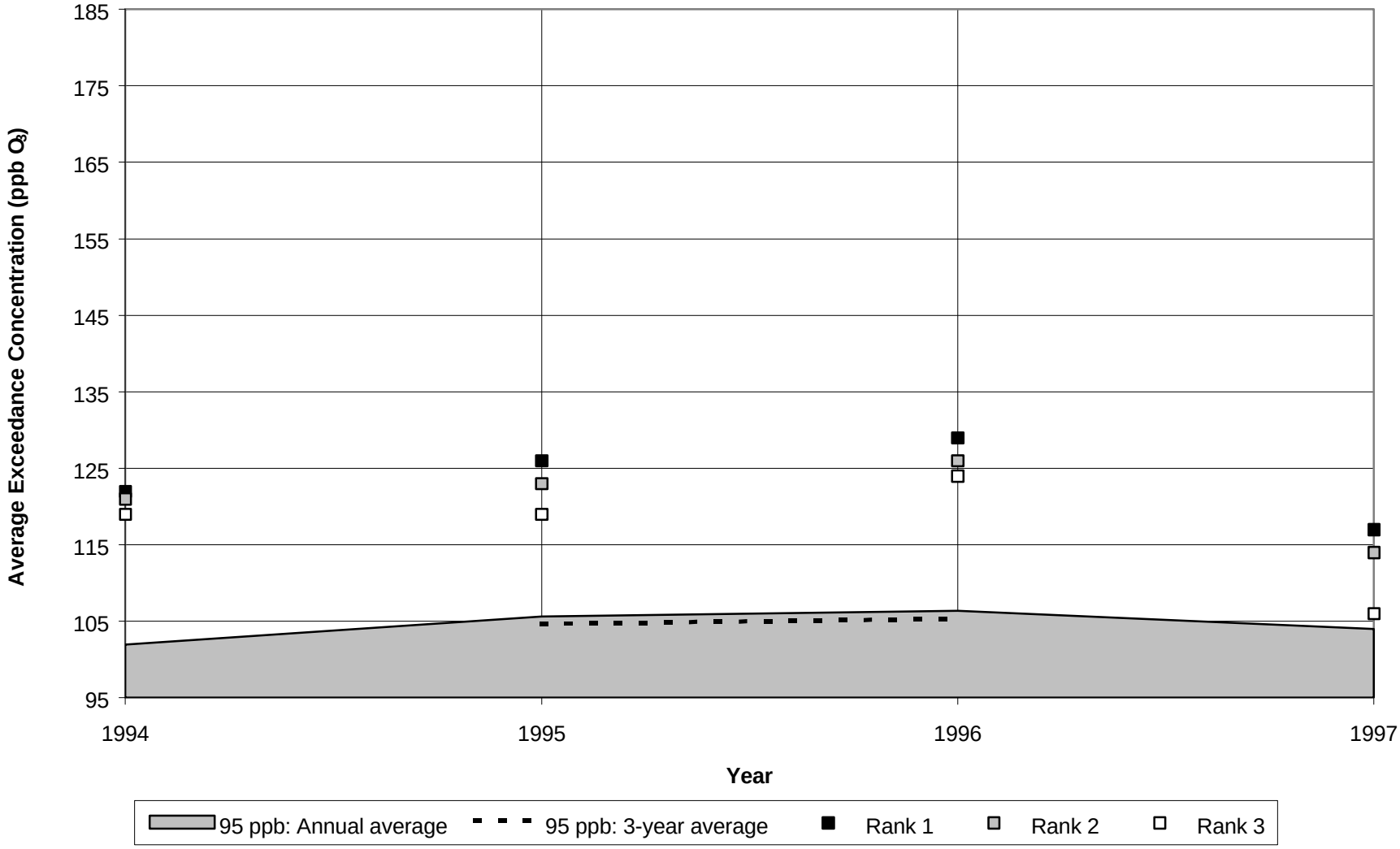
Golden State - Exceedances of the California Ozone Standard with analysis uncertainty.



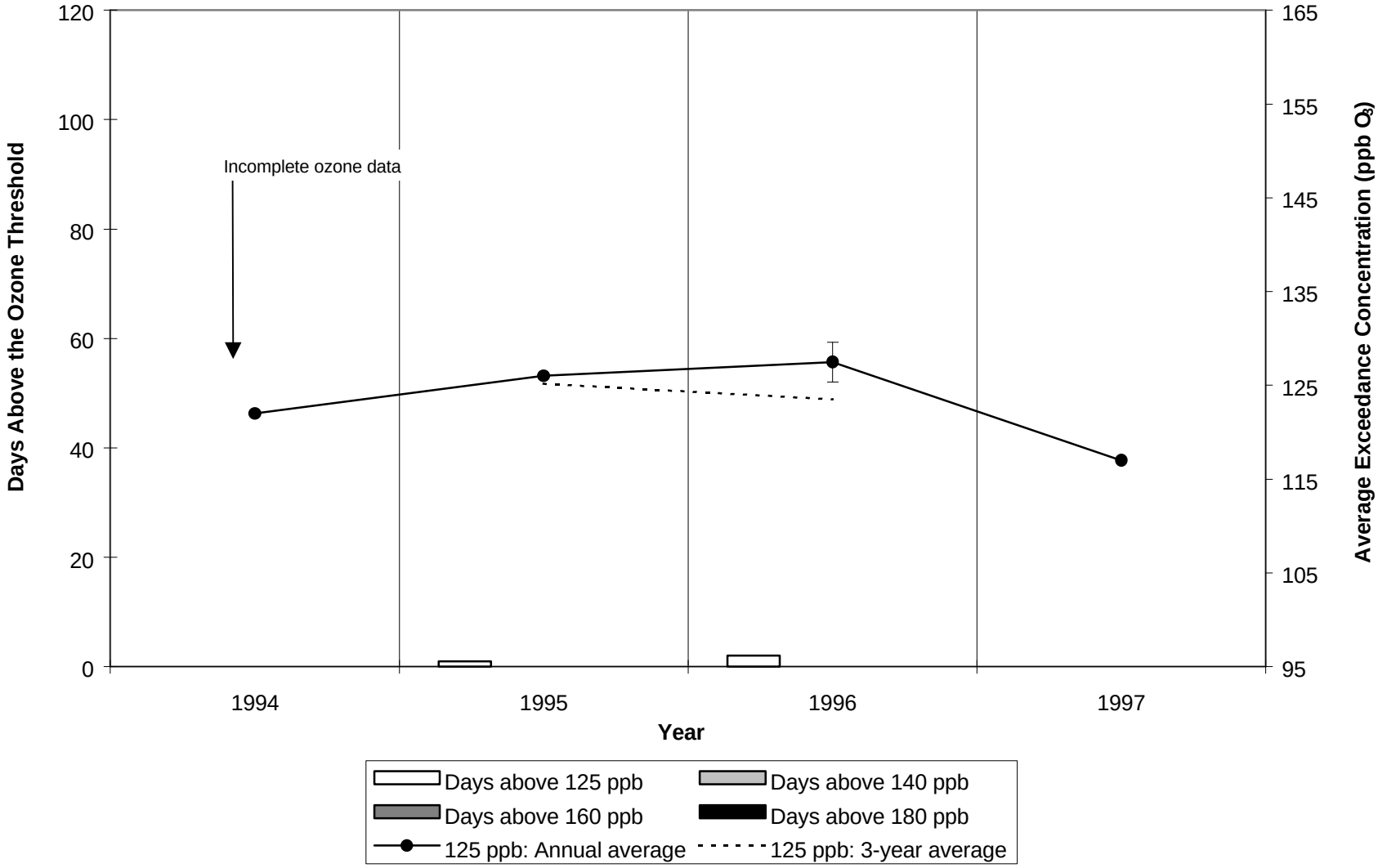
Golden State - Total number of exceedances of the California Ozone Standard.



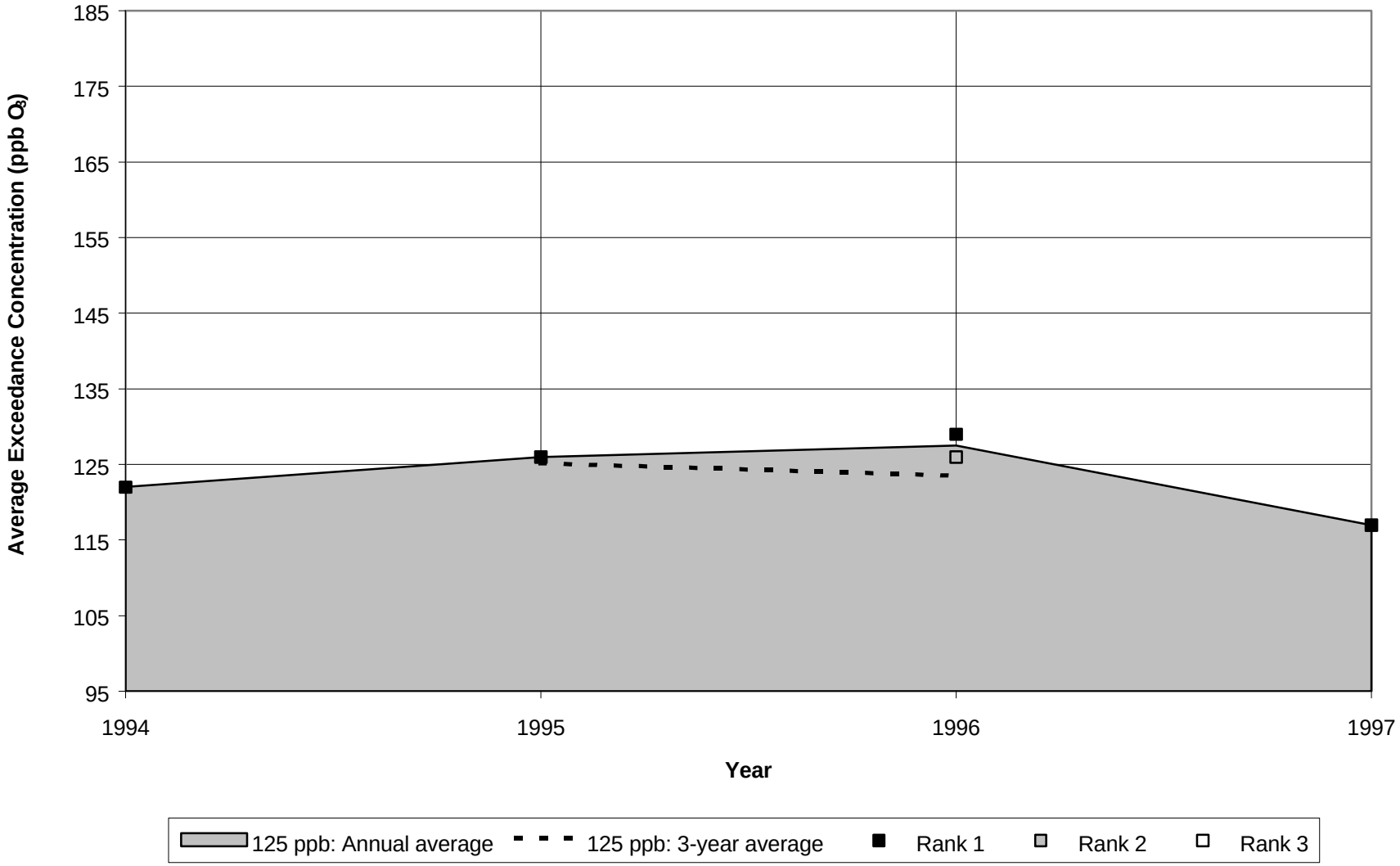
Golden State - Identification of the highest exceedance concentrations of the California Ozone Standard.



Golden State - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty.



Golden State - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.



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APPENDIX D

ADDITIONAL FRESNO ANALYSES

Statistical techniques were applied to three Fresno sites: Clovis-Villa (PAMS Type 2 site), Parlier (PAMS Type 3 site), and Fresno 1st Street (PAMS Type 2-like ARB site). The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS that occurred at the Parlier site were detailed in Section 6 of the report. The following figures are presented in this Appendix and parallel the analyses of the Parlier site data and the 1-hr Ozone NAAQS that was presented in Section 6:

- Parlier - Exceedances of the California Ozone Standard with analysis uncertainty.
- Parlier - Total number of exceedances of the California Ozone Standard.
- Parlier - Identification of the highest exceedance concentrations of the California Ozone Standard.
- Parlier - Number and ratio of the number of the exceedance days of the California Ozone Standard by meteorology.
- Clovis-Villa – Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentration.

The following figures are presented in this Appendix and pertain to additional analyses of ozone trends that were performed for the Clovis-Villa and Fresno 1st Street sites. The figures for each site are presented separately in the following order:

- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the California Ozone Standard.
- Identification of the highest exceedance concentrations of the California Ozone Standard.
- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the 1-hr Ozone NAAQS.
- Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS.

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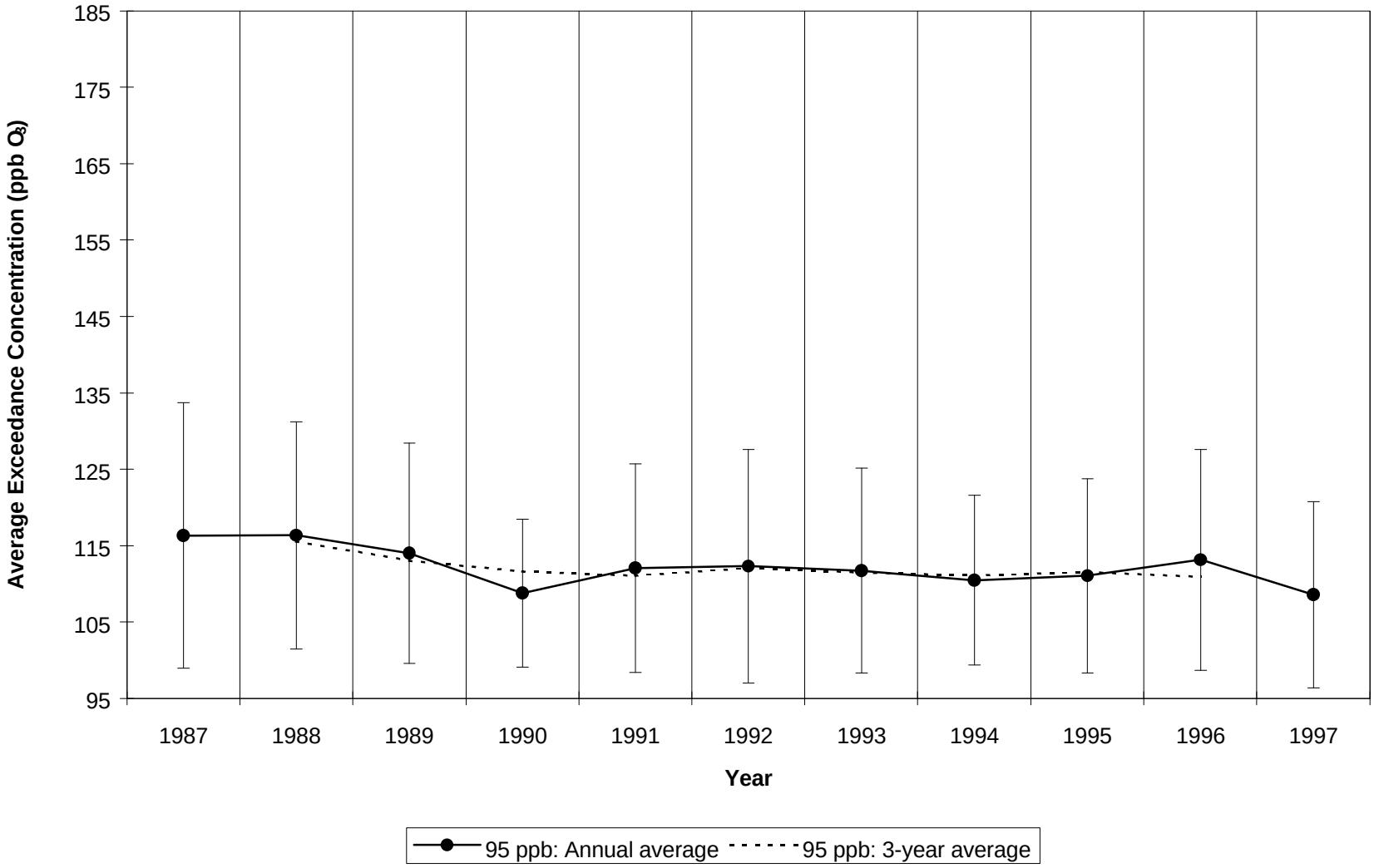
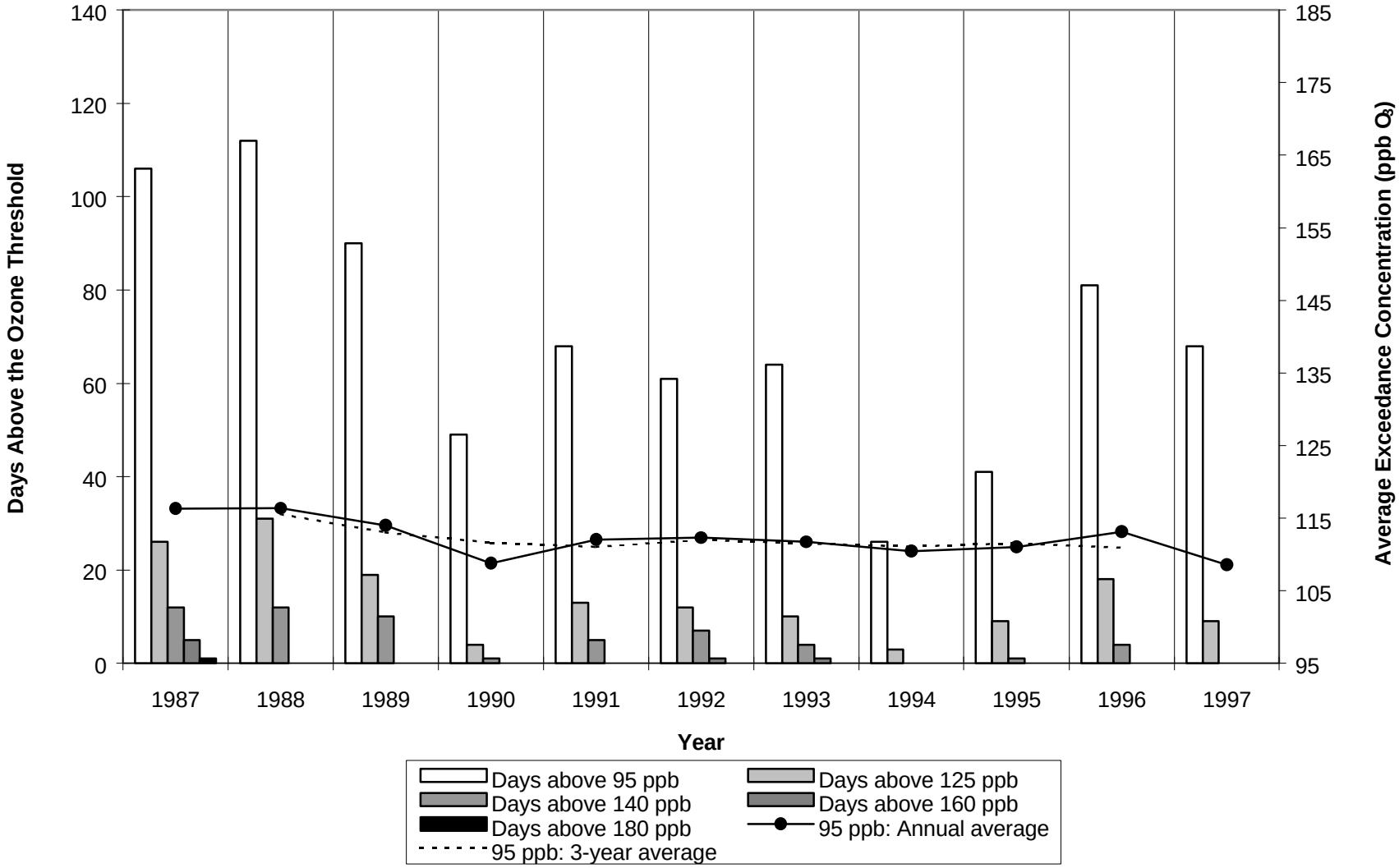
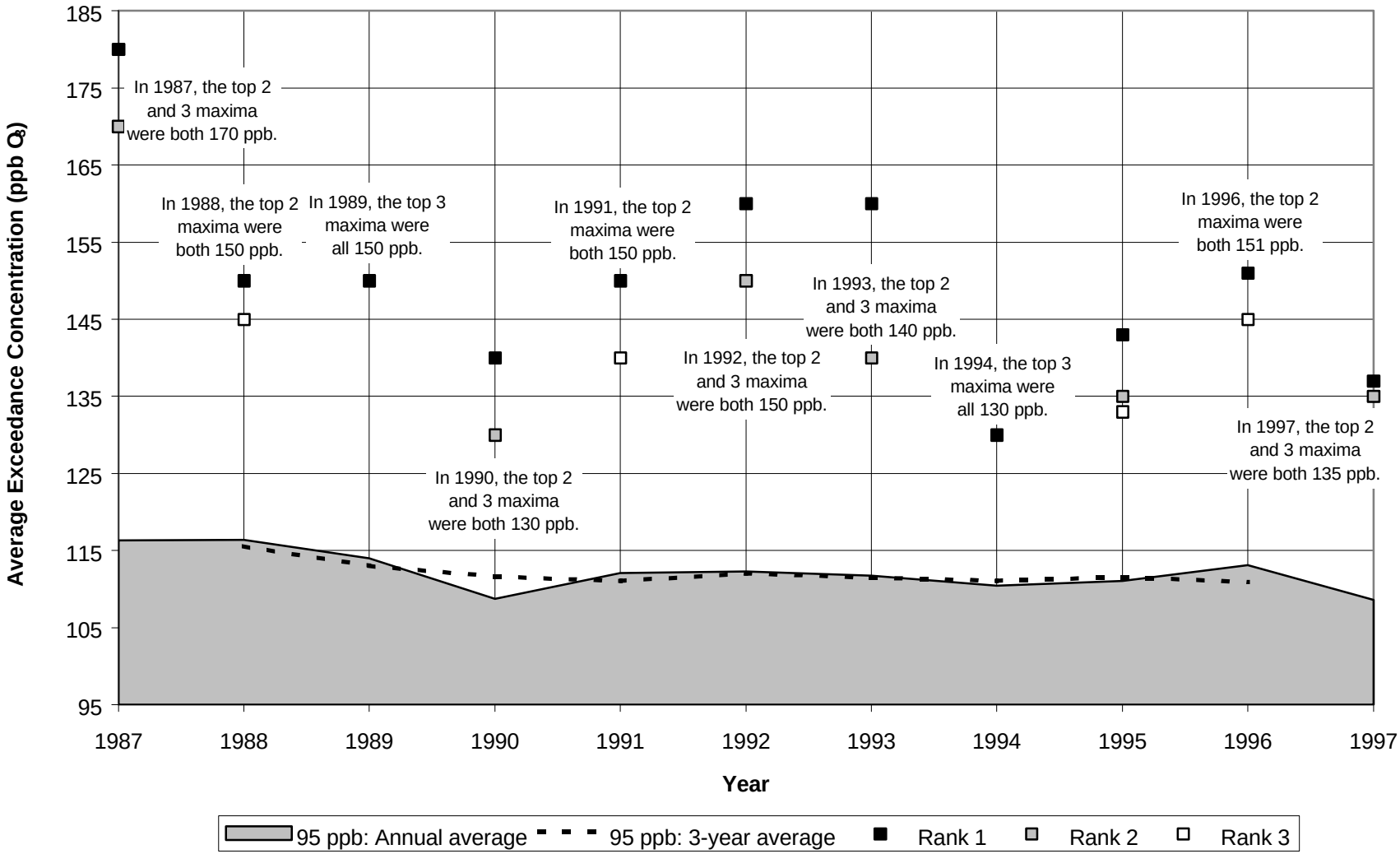
Parlier - Exceedances of the California Ozone Standard with analysis uncertainty,



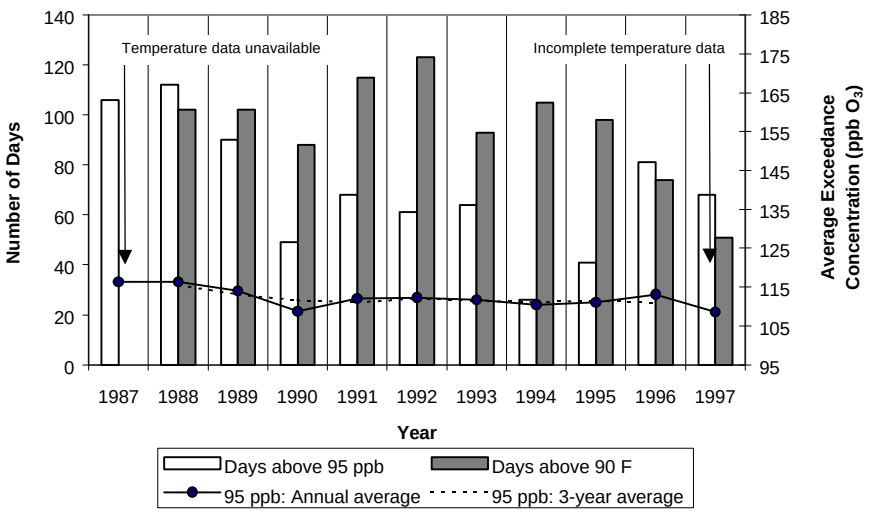
Parlier - Total number of exceedances of the California Ozone Standard.

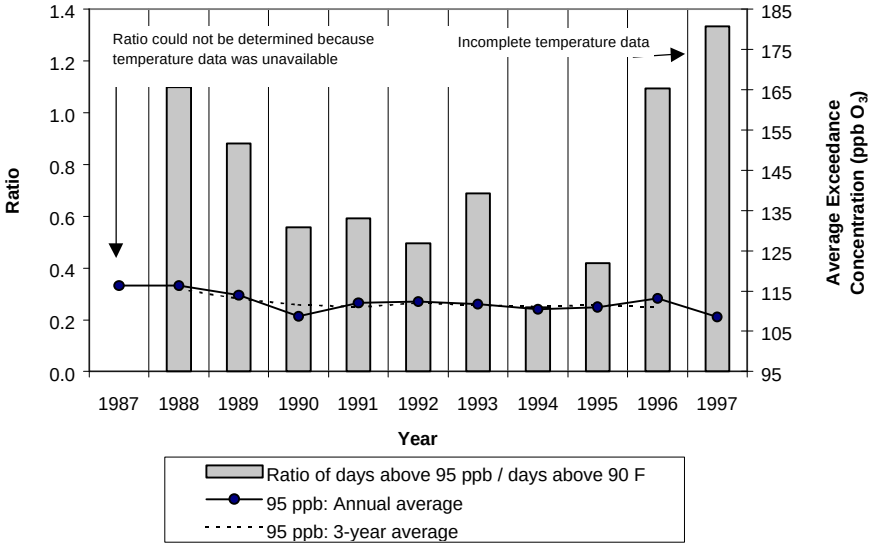


Parlier - Identification of the highest exceedance concentrations of the California Ozone Standard.

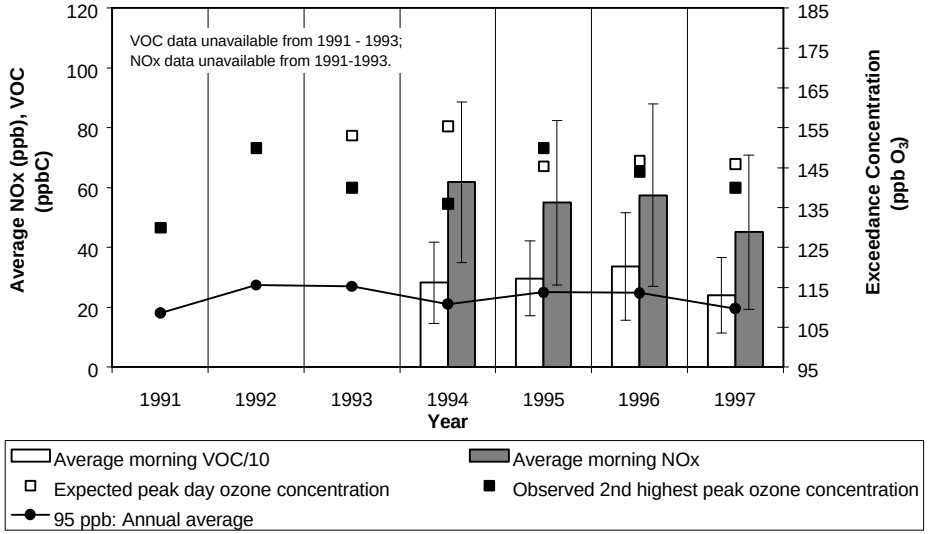


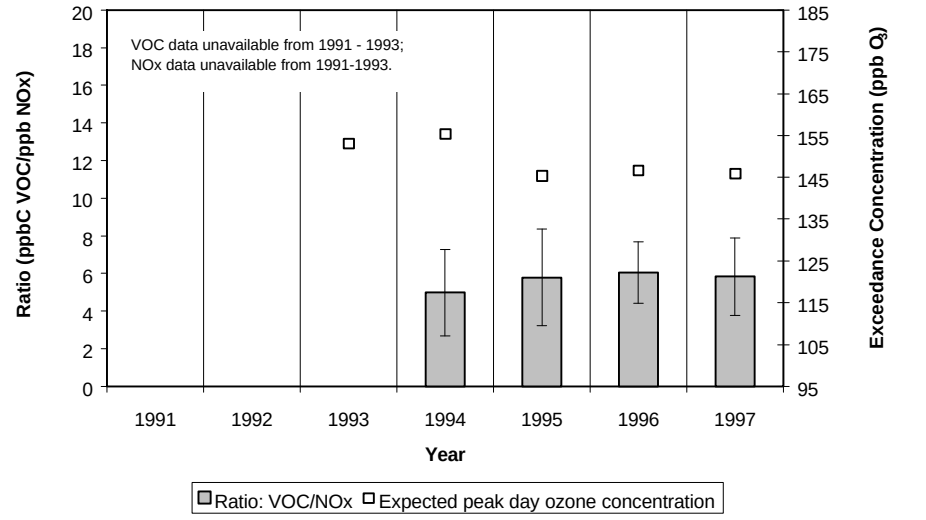
Parlier - Number and fraction of the exceedances of the California Ozone Standard by meteorology.



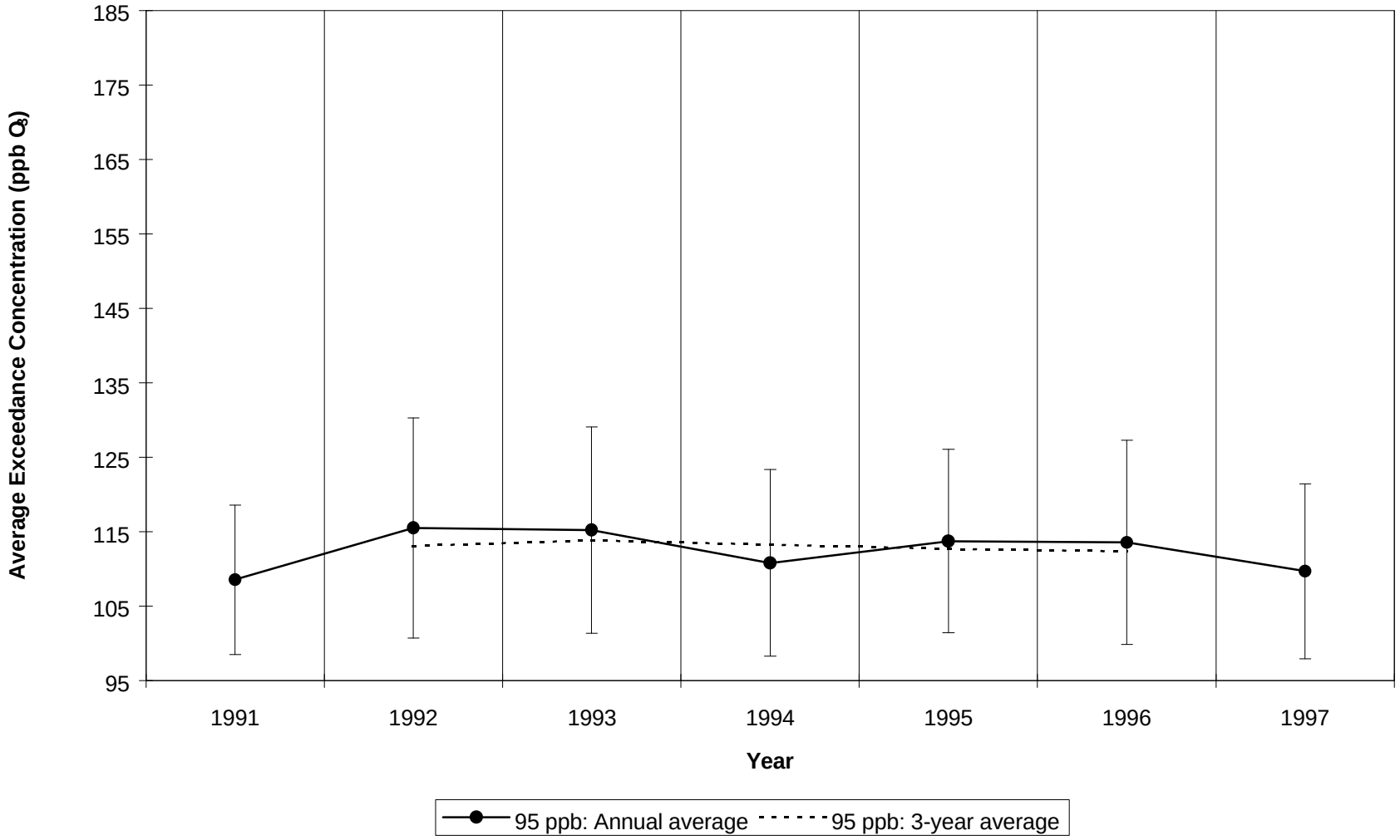


Clovis-Villa - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor

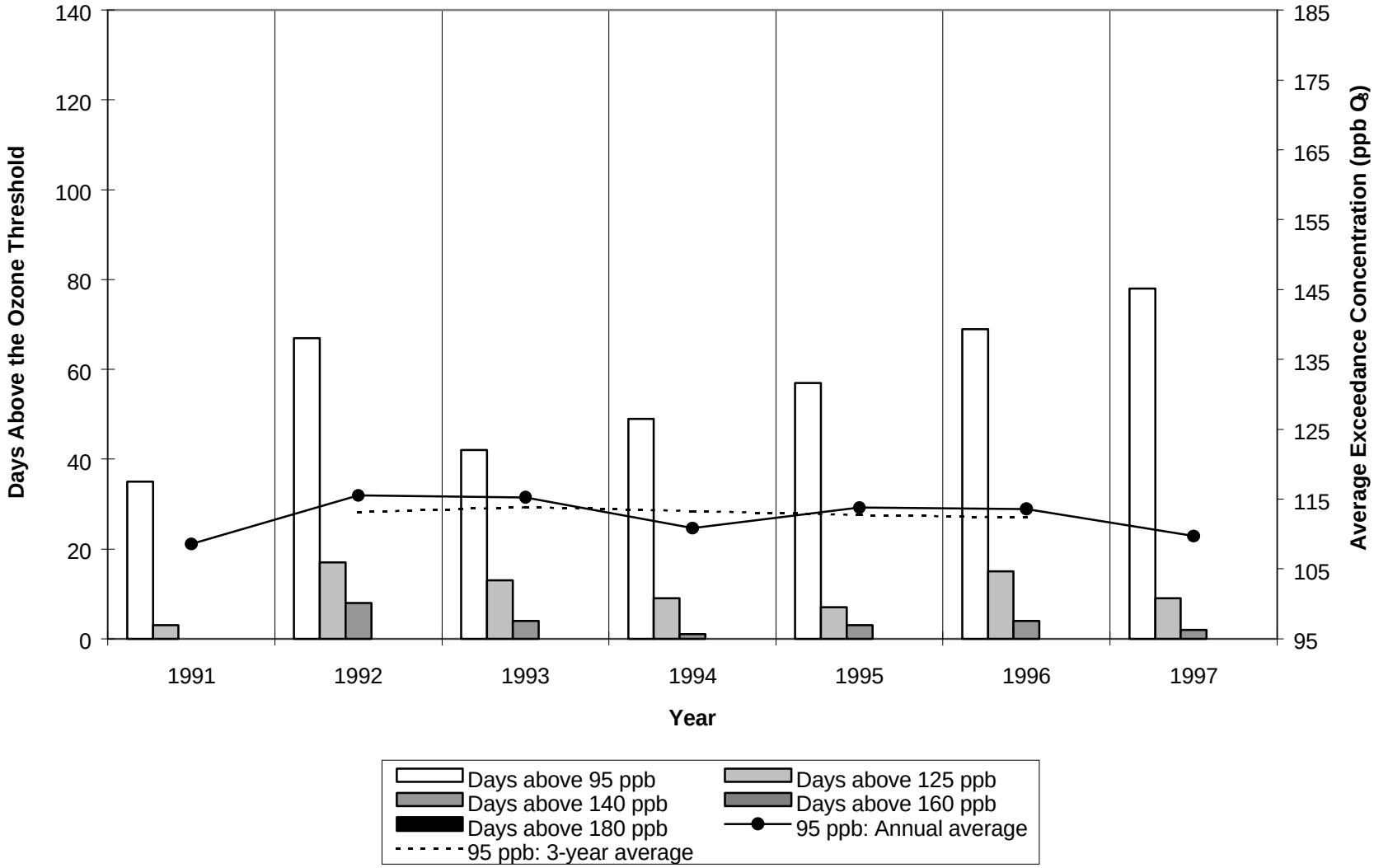




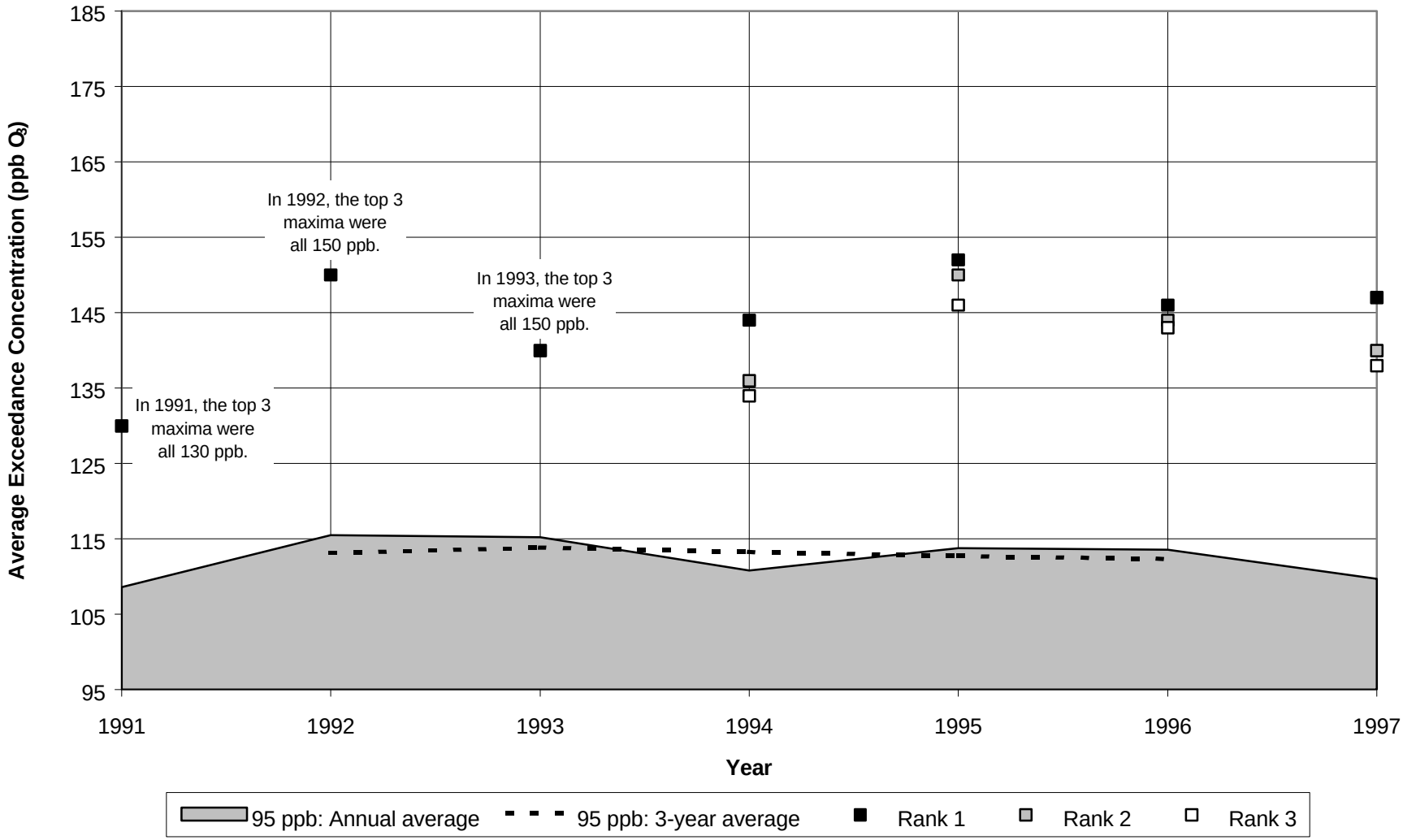
Clovis-Villa - Exceedances of the California Ozone Standard with analysis uncertainty,

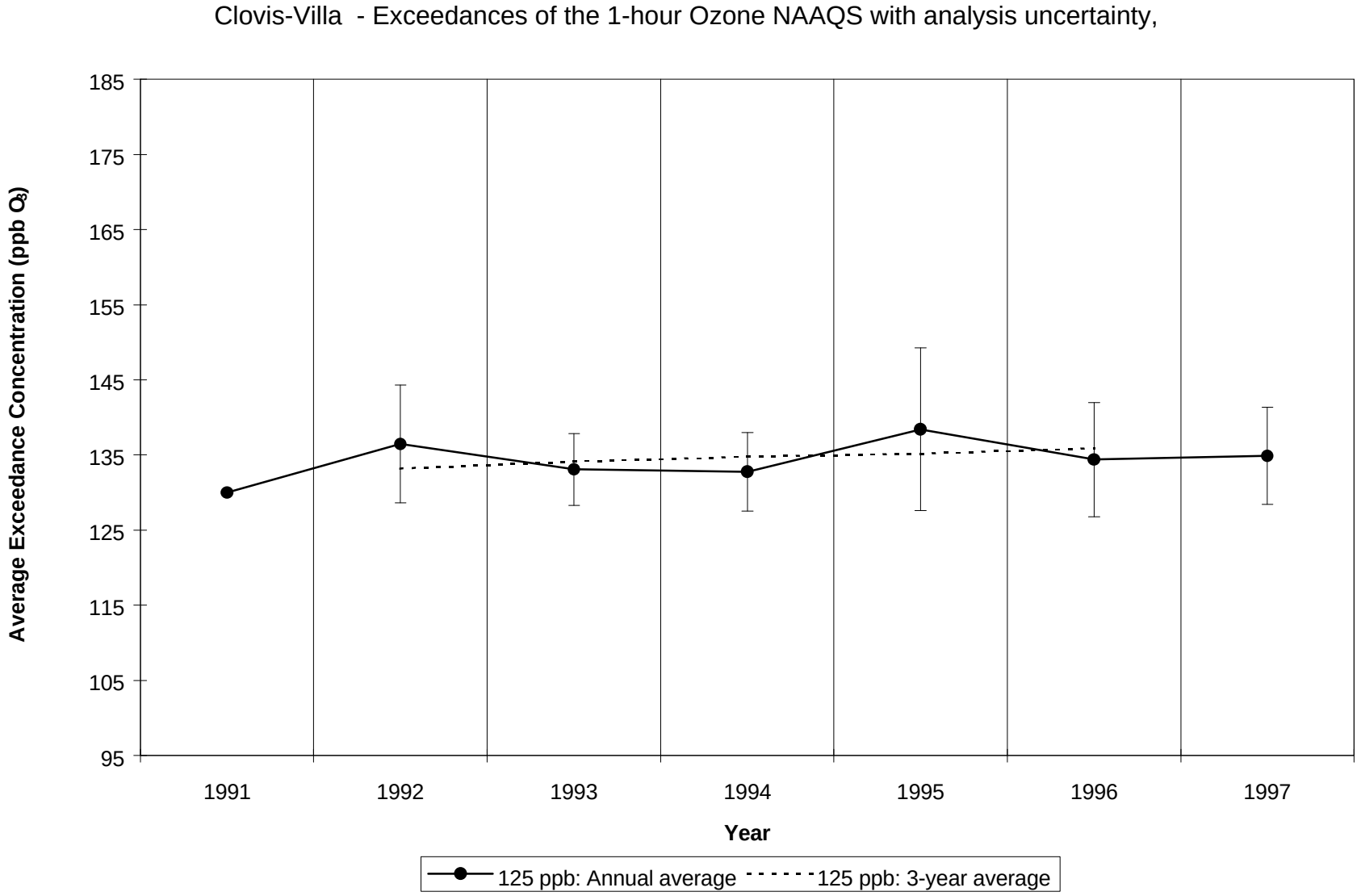


Clovis-Villa - Total number of exceedances of the California Ozone Standard.

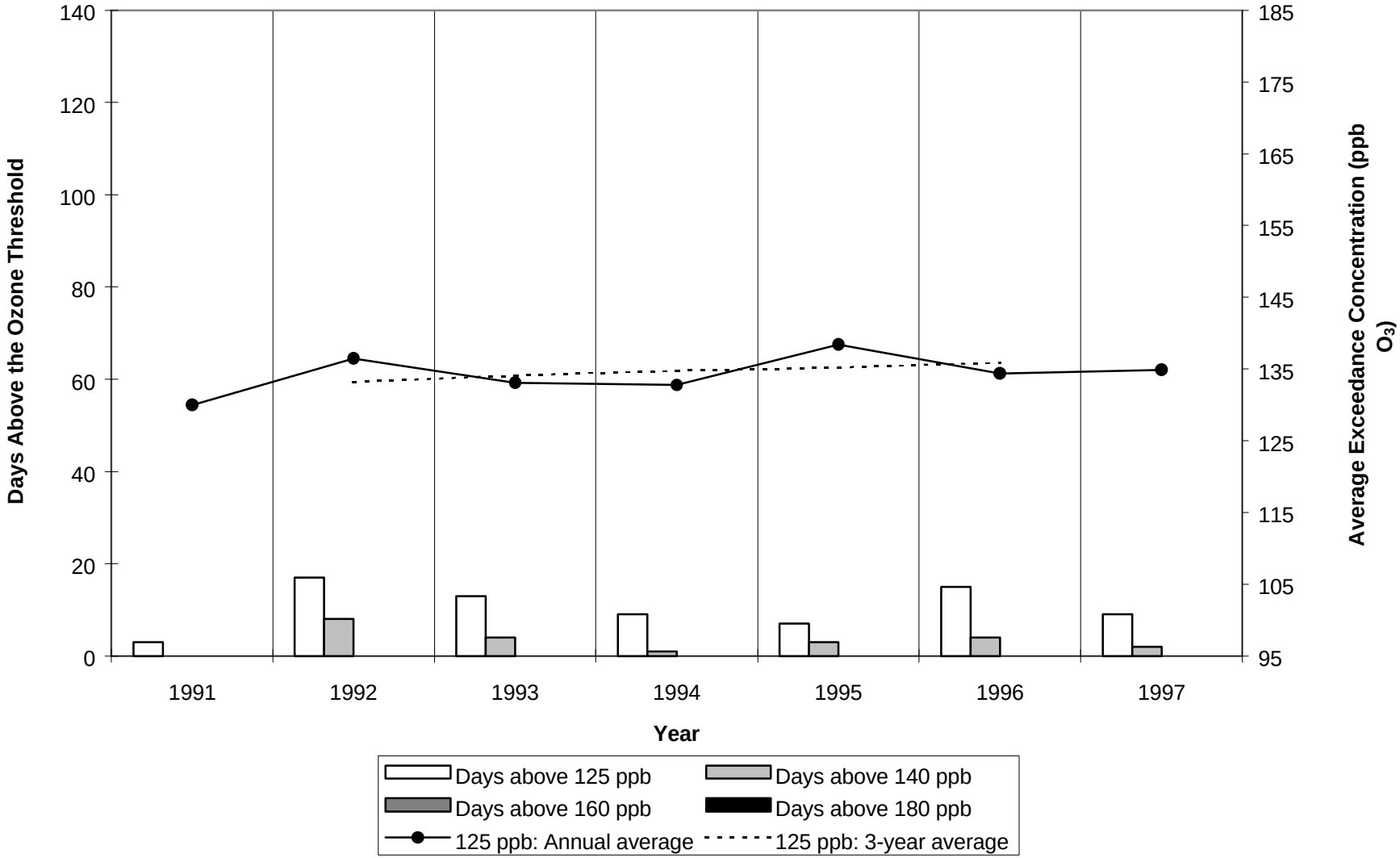


Clovis-Villa - Identification of the highest exceedance concentrations of the California Ozone Standard.

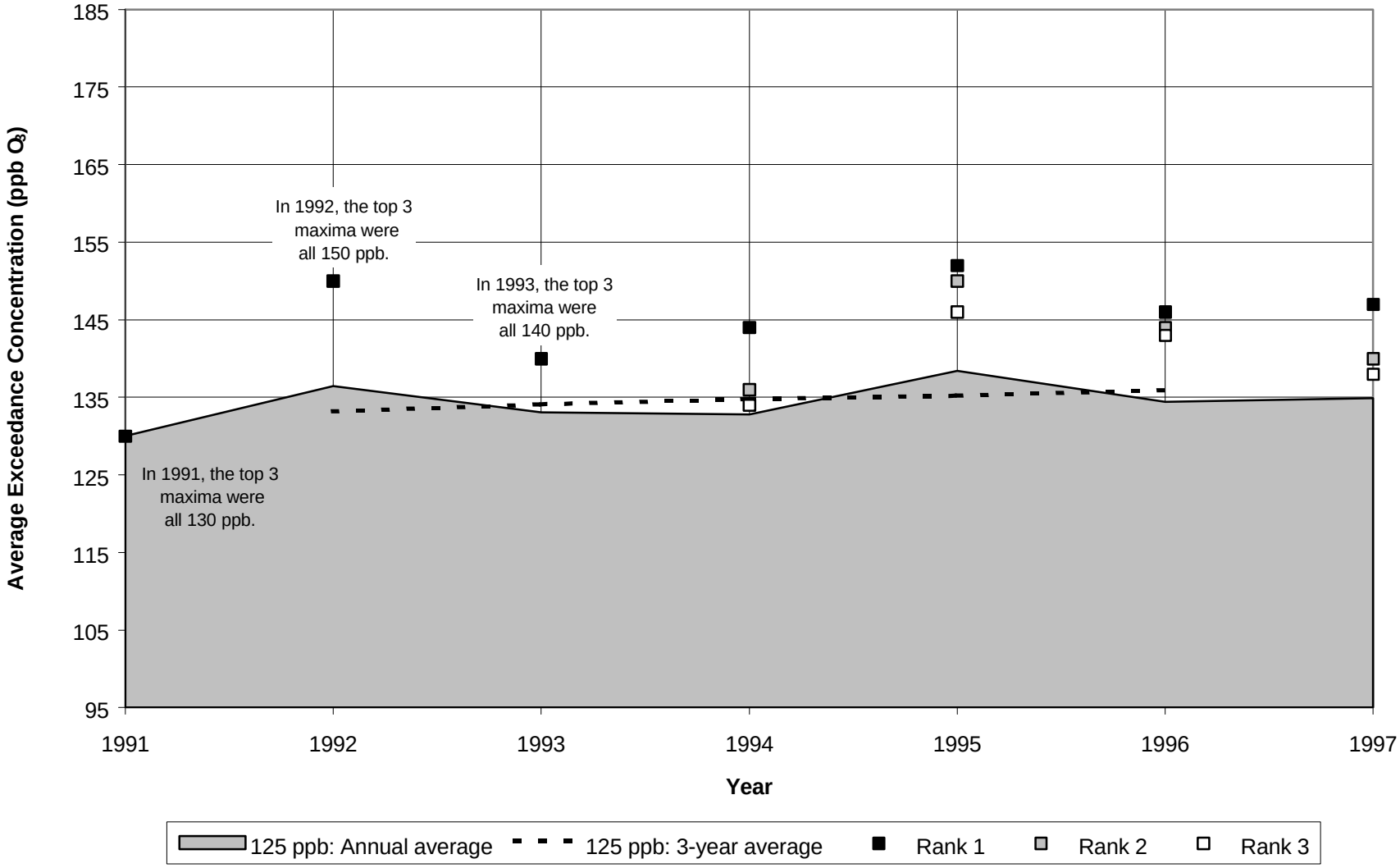



Clovis-Villa - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty,
Average Exceedance Concentration (ppb O3)
185
175
165
155
145
135
125
115
105
95
1991
1992
1993
1994
1995
1996
1997
Year
125 ppb: Annual average
125 ppb: 3-year average

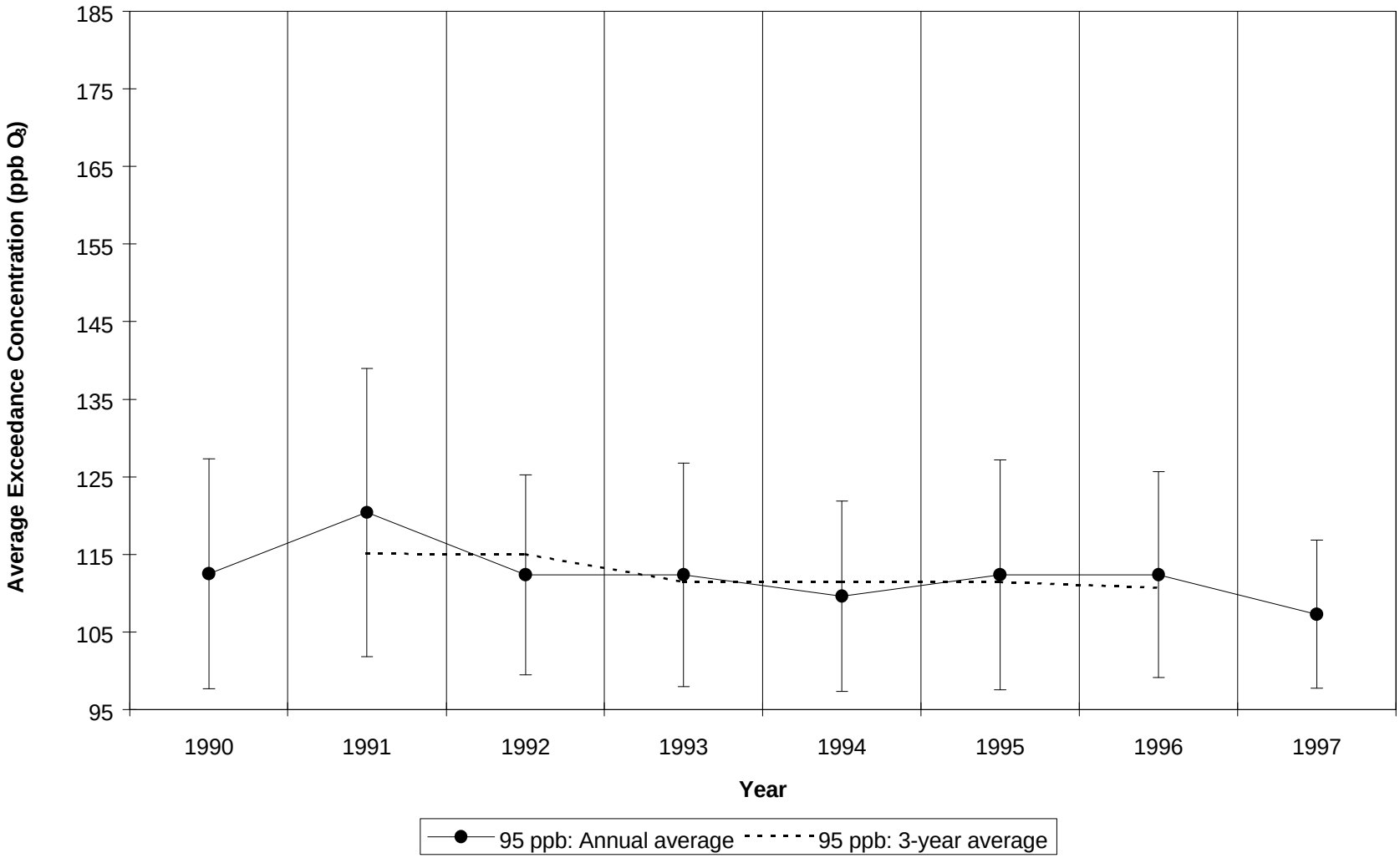
Clovis-Villa - Total number of exceedances of the 1-hour Ozone NAAQS.

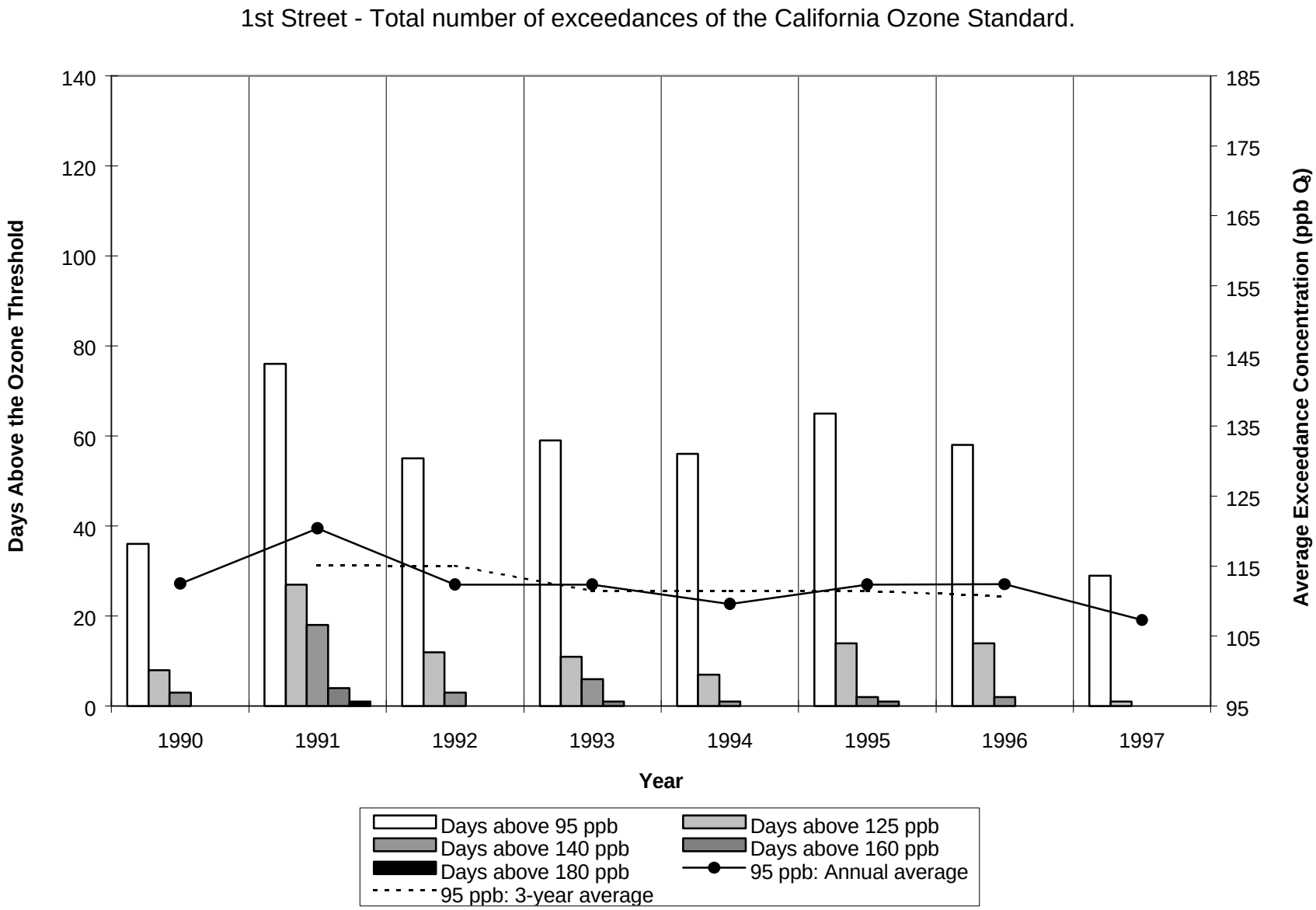


Clovis-Villa - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.

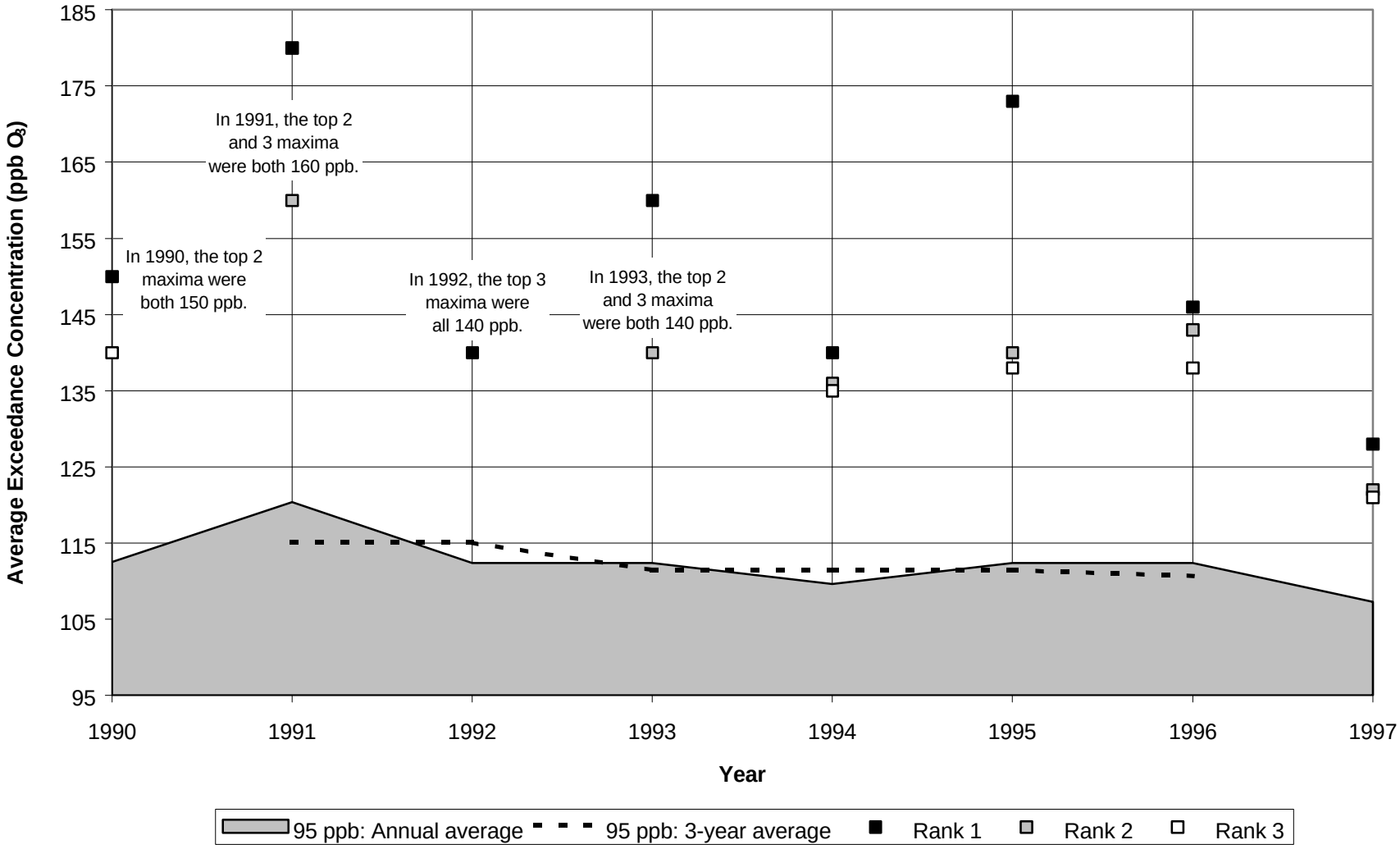


1st Street - Exceedances of the California Ozone Standard with analysis uncertainty,

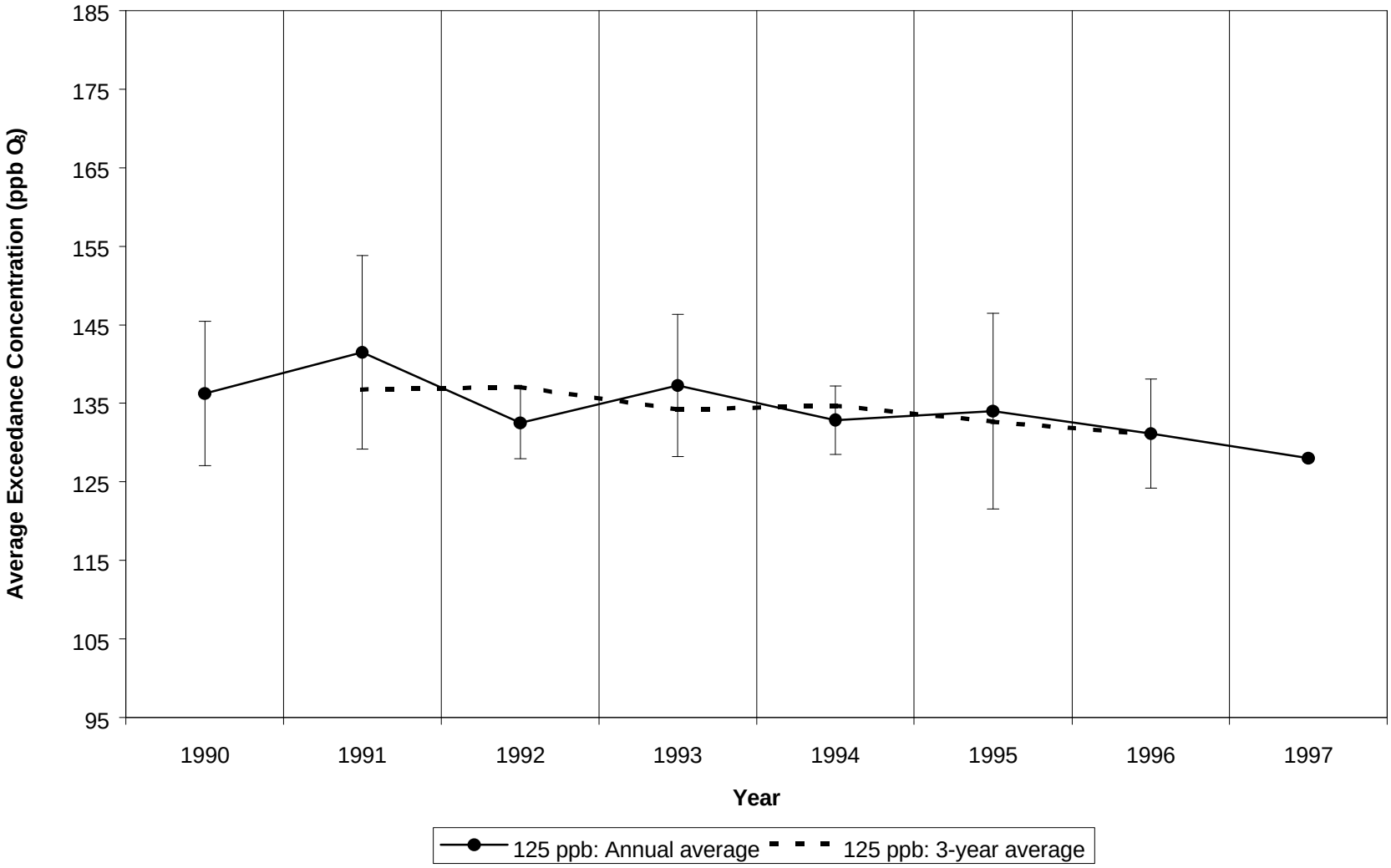



1st Street - Total number of exceedances of the California Ozone Standard.
Days Above the Ozone Threshold
Average Exceedance Concentration (ppb O3)
Year
0
20
40
60
80
100
120
140
95
105
115
125
135
145
155
165
175
185
1990
1991
1992
1993
1994
1995
1996
1997
Days above 95 ppb
Days above 125 ppb
Days above 140 ppb
Days above 160 ppb
Days above 180 ppb
95 ppb: Annual average
95 ppb: 3-year average

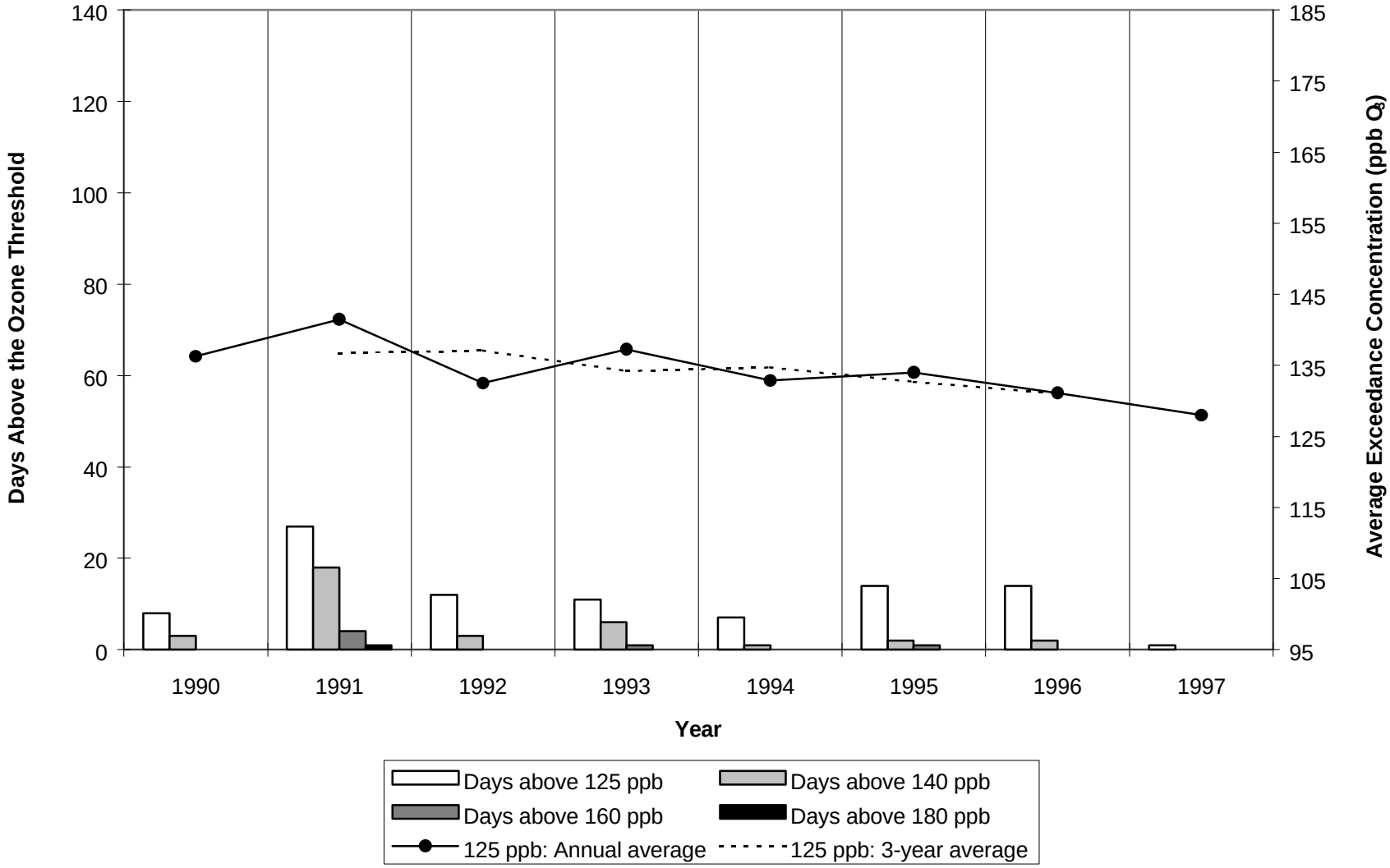
1st Street - Identification of the highest exceedance concentrations of the California Ozone Standard.



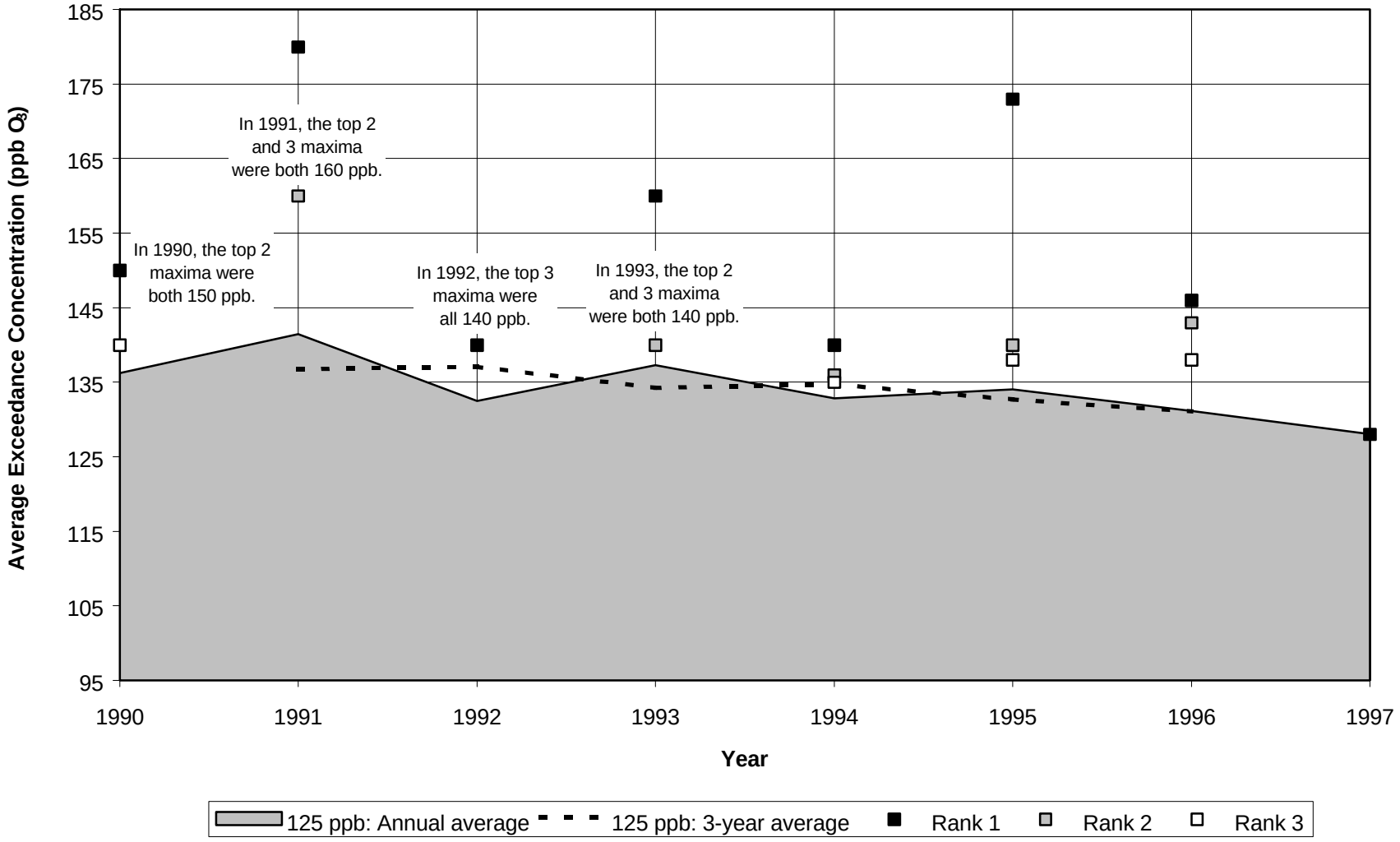
1st Street - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty,



1st Street - Total number of exceedances of the 1-hour Ozone NAAQS.



1st Street - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.



APPENDIX E

ADDITIONAL LOS ANGELES ANALYSES

Statistical techniques were applied to the PAMS Type 2-like Los Angeles North Main Street site. The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS were detailed in Section 7 of the report. The following figures are presented in this Appendix and parallel the analyses of the North Main Street site data and the 1-hr Ozone NAAQS that was presented in Section 7:

- North Main - Exceedances of the California Ozone Standard with analysis uncertainty.
- North Main - Total number of exceedances of the California Ozone Standard.
- North Main - Identification of the highest exceedance concentrations of the California Ozone Standard.
- North Main - Number and ratio of the number of the exceedance days of the California Ozone Standard by meteorology.
- North Main - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentration.

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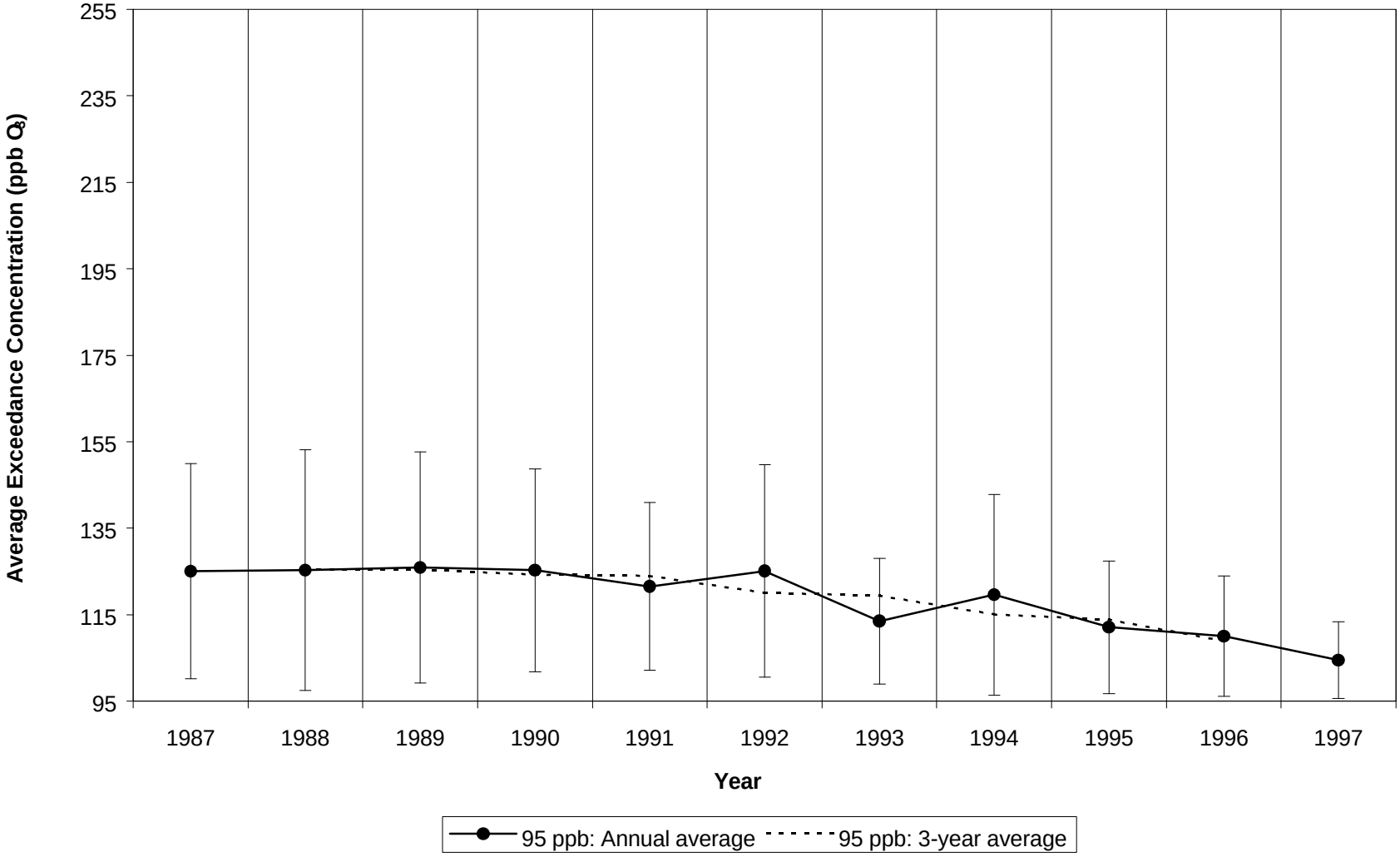
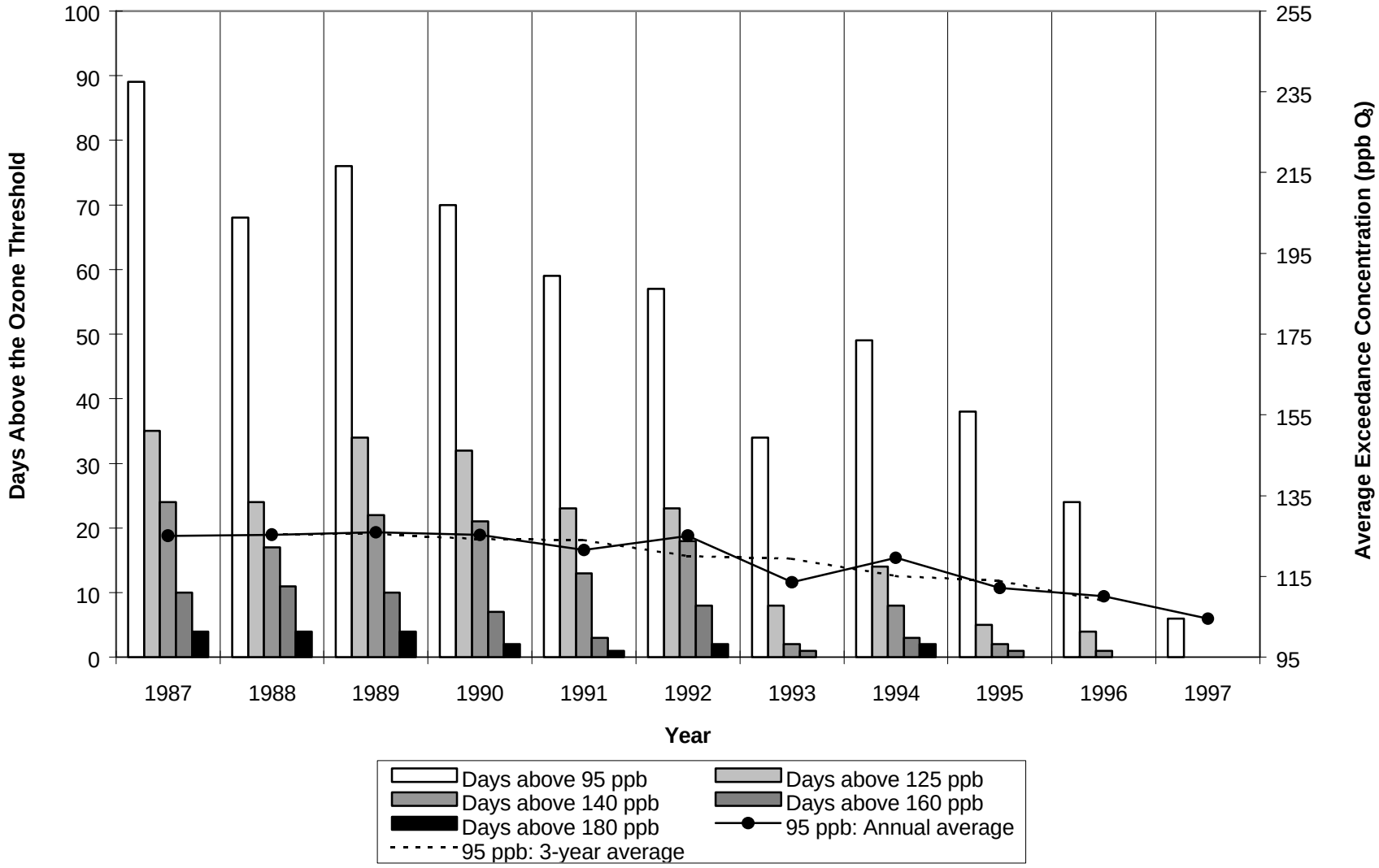
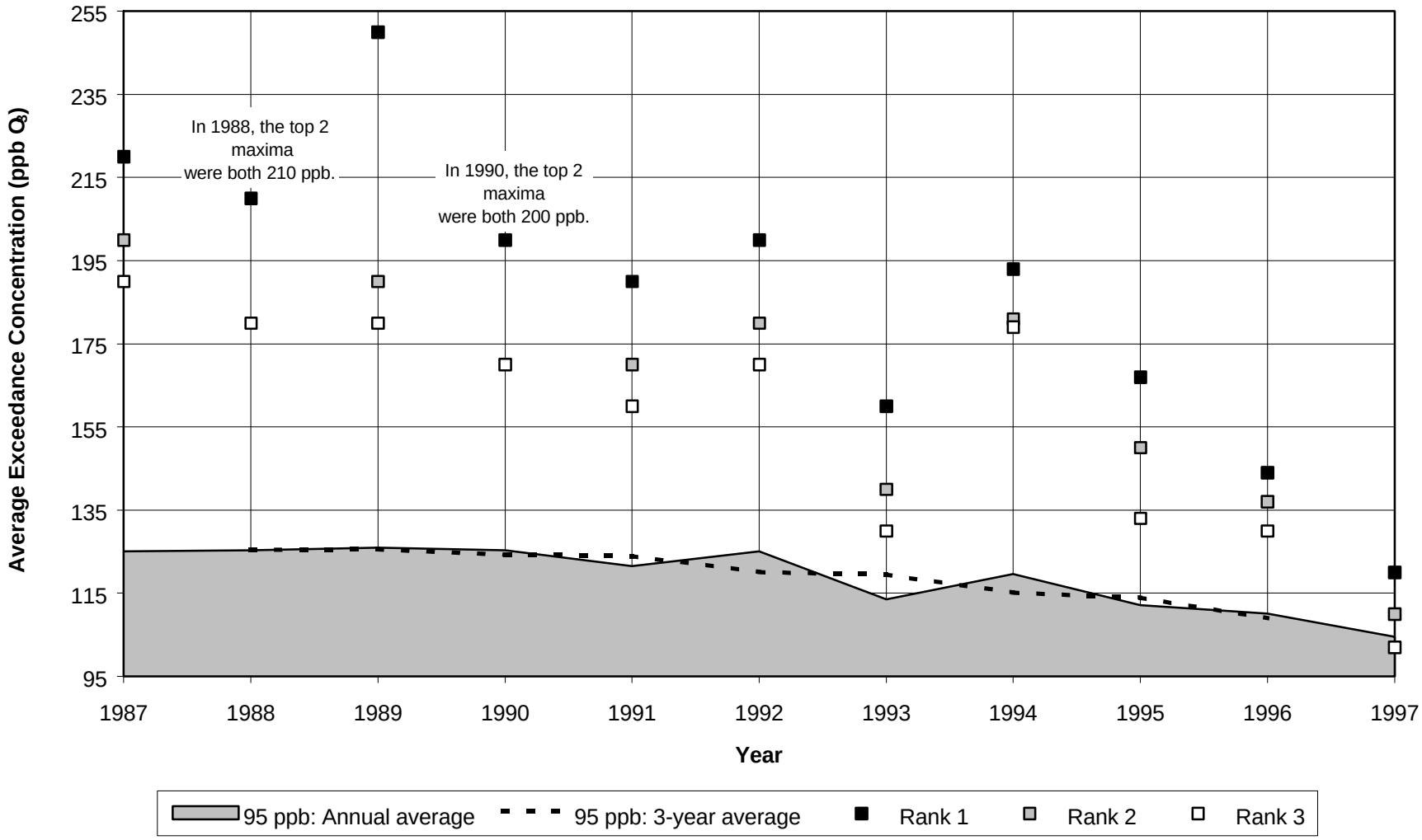
North Main Street - Exceedances of the California Ozone Standard with analysis uncertainty.



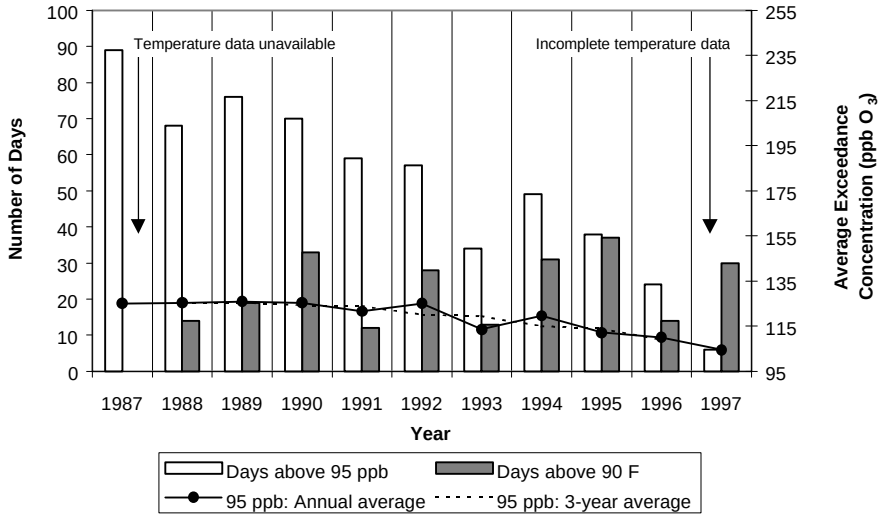
North Main Street - Total number of exceedances of the California Ozone Standard.

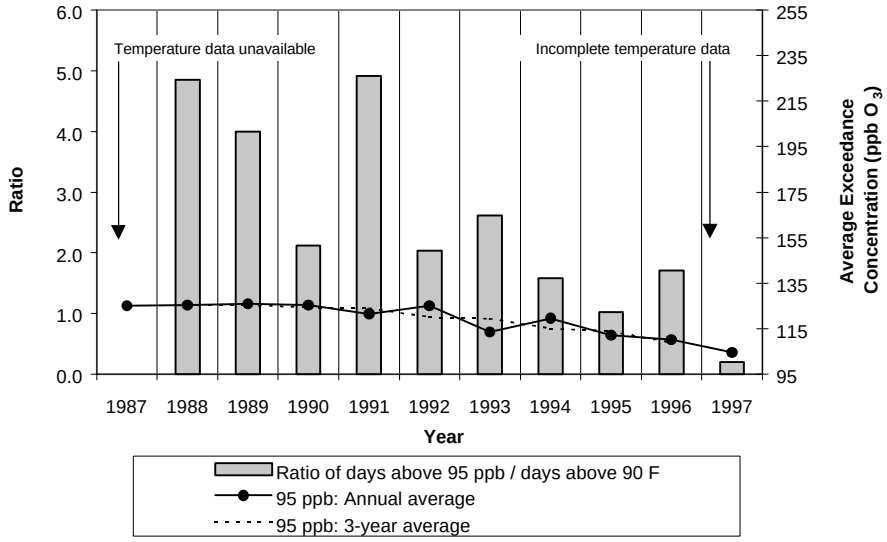


North Main Street - Identification of the highest exceedance concentrations of the California Ozone Standard.

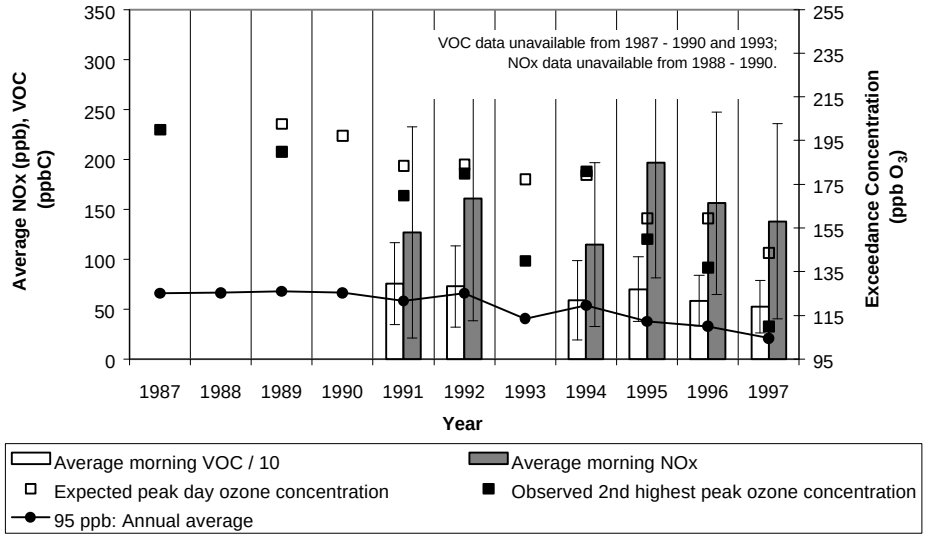


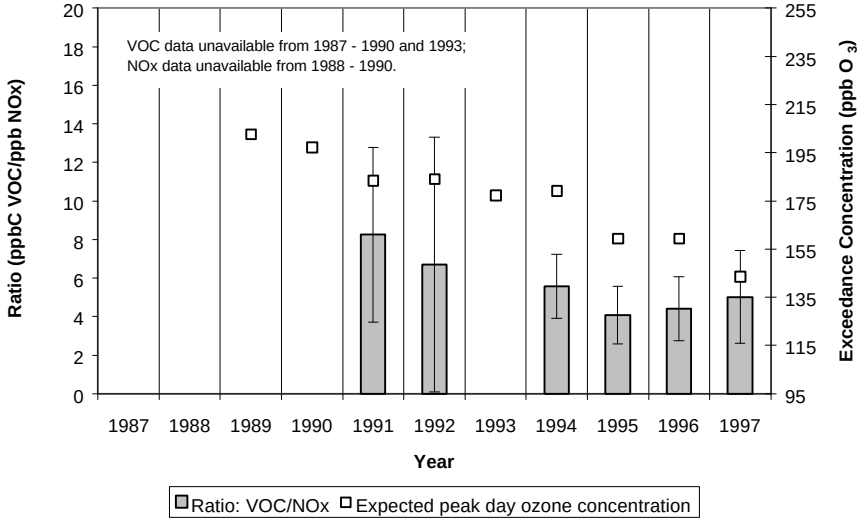
North Main Street - Number and fraction of the exceedances of the California Ozone Standard by meteorology.





North Main Street - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentrations.





APPENDIX F

ADDITIONAL SAN DIEGO ANALYSES

Statistical techniques were applied to the PAMS Type 2-like San Diego 12th Street site. The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS were detailed in Section 8 of the report. The following figures are presented in this Appendix and parallel the analyses of the 12th Street site data and the 1-hr Ozone NAAQS that was presented in Section 8:

- 12th Street - Exceedances of the California Ozone Standard with analysis uncertainty.
- 12th Street - Total number of exceedances of the California Ozone Standard.
- 12th Street - Identification of the highest exceedance concentrations of the California Ozone Standard.
- 12th Street - Number and ratio of the number of the exceedance days of the California Ozone Standard by meteorology.
- 12th Street - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentration.

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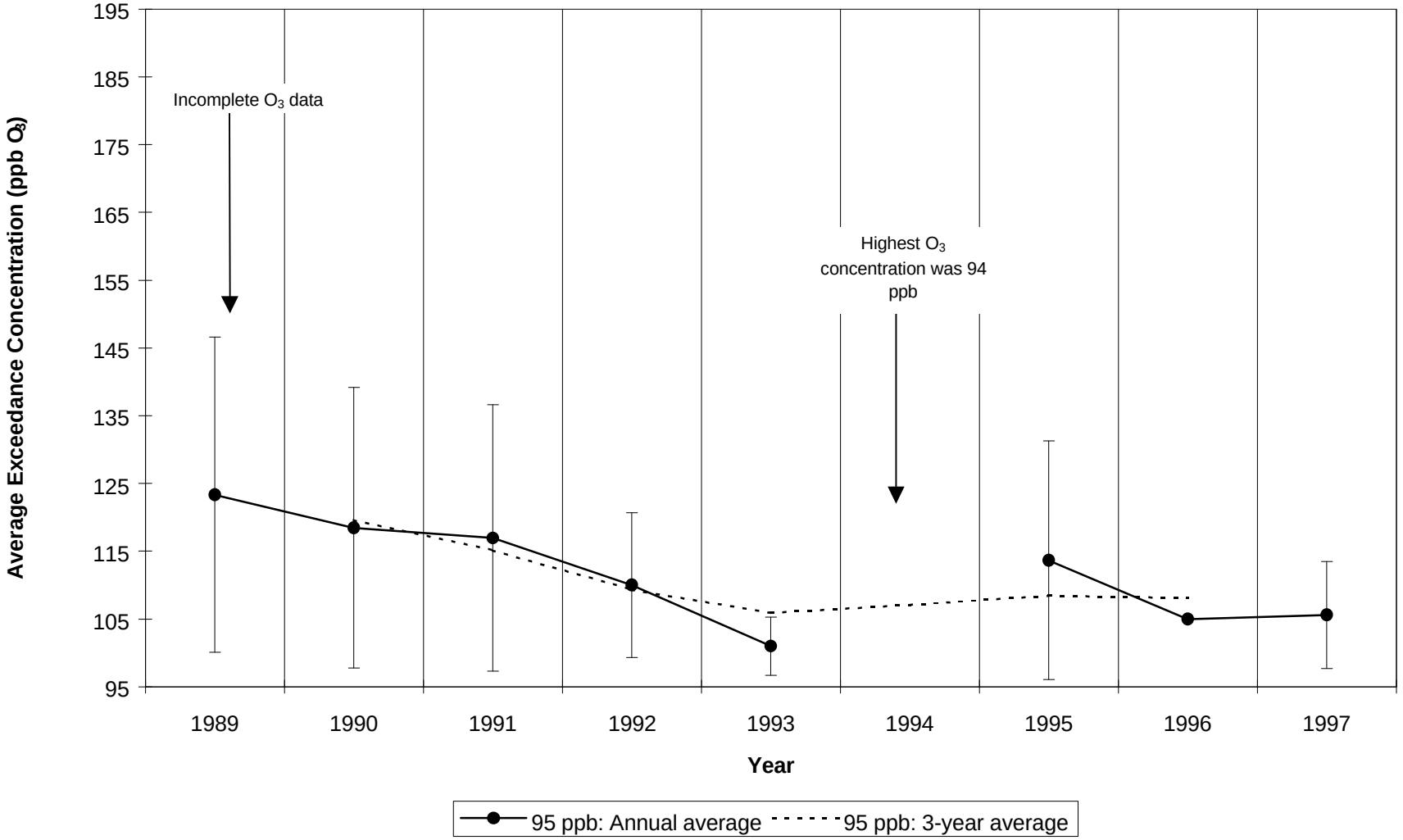
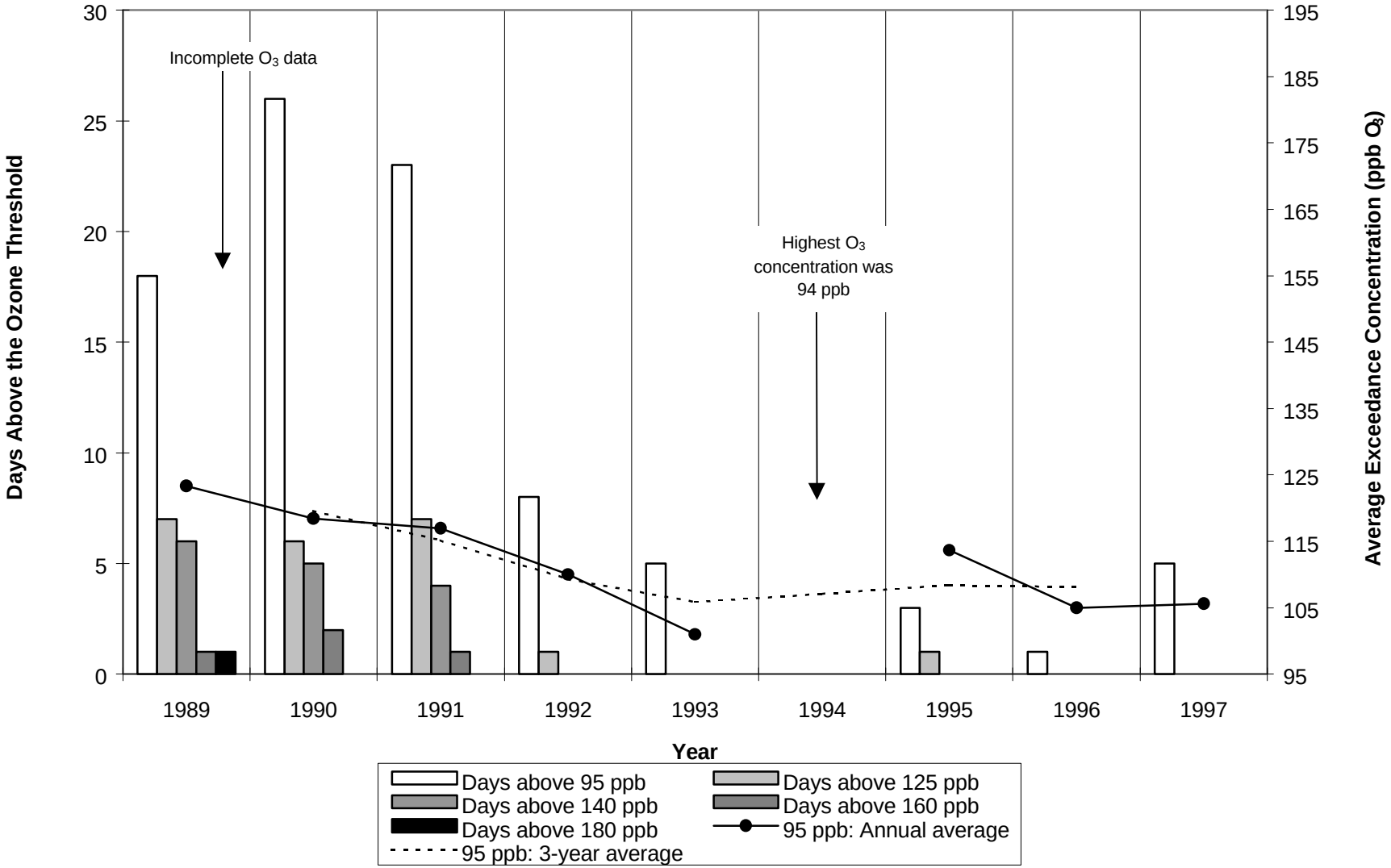
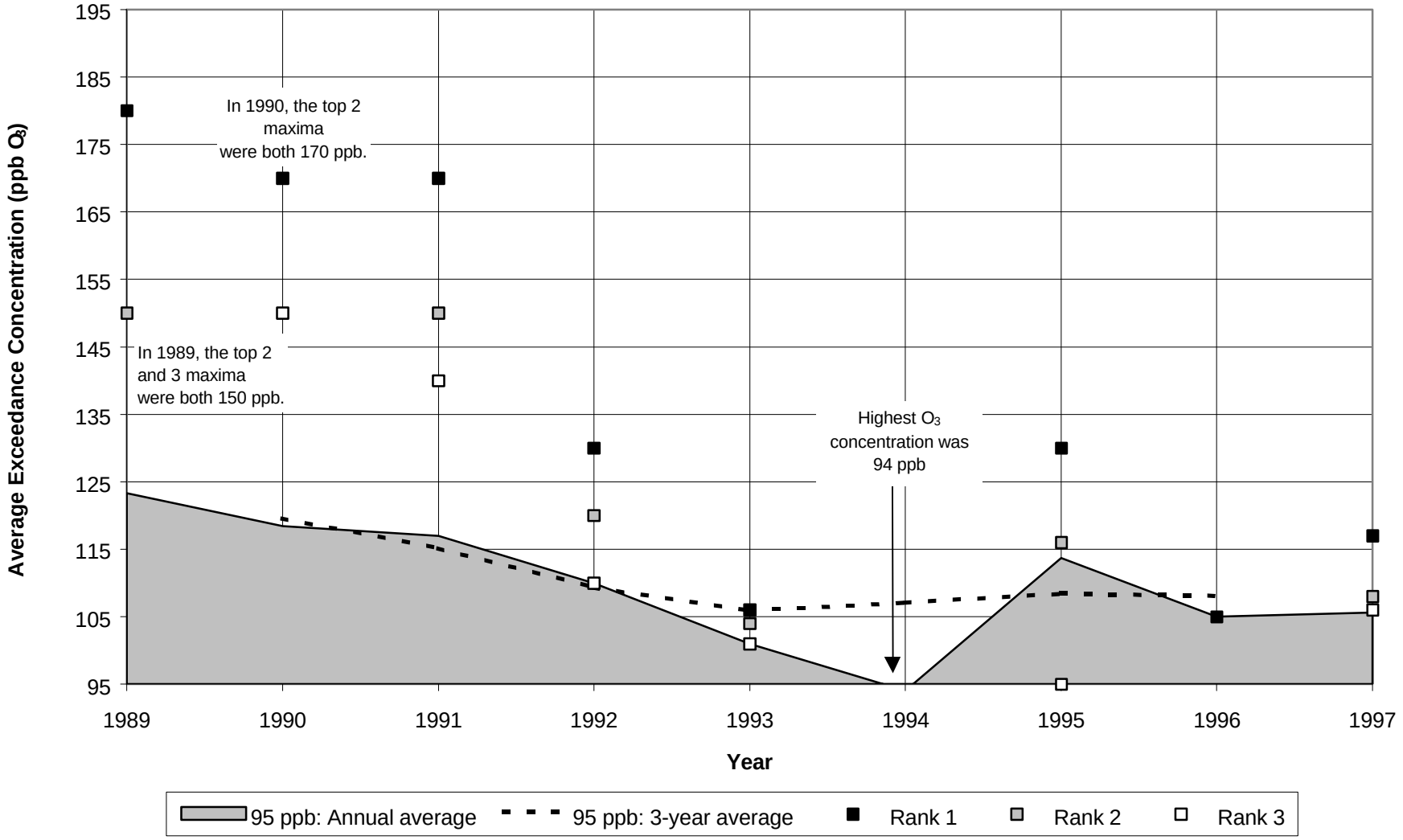
12th Street - Exceedances of the California Ozone Standard with analysis uncertainty.



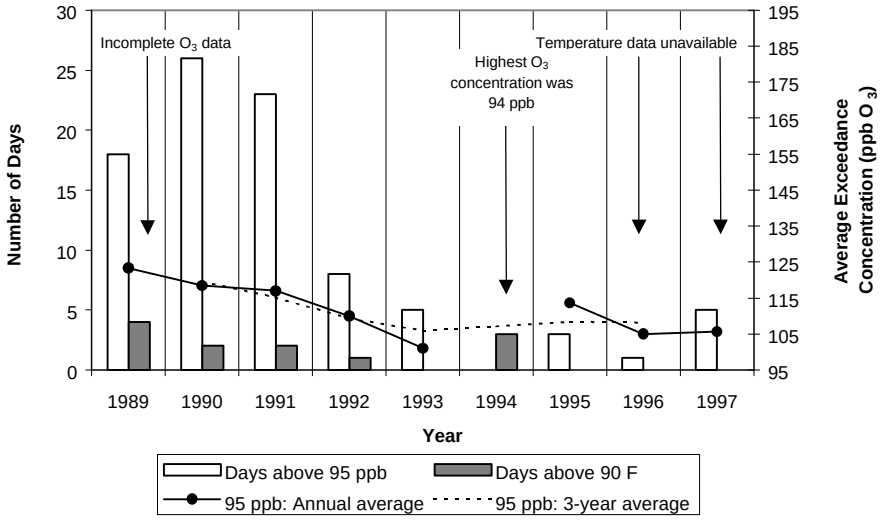
12th Street - Total number of exceedances of the California Ozone Standard.

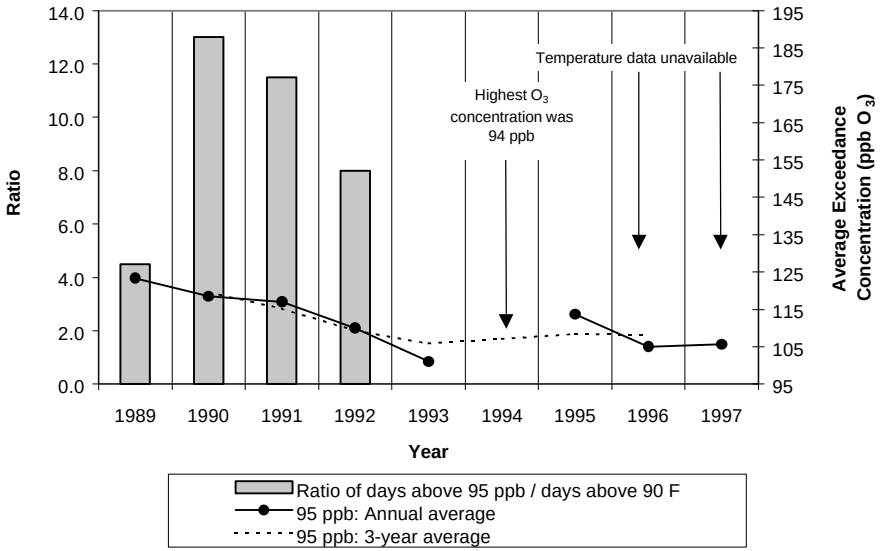


12th Street - Identification of the highest exceedance concentrations of the California Ozone Standard.

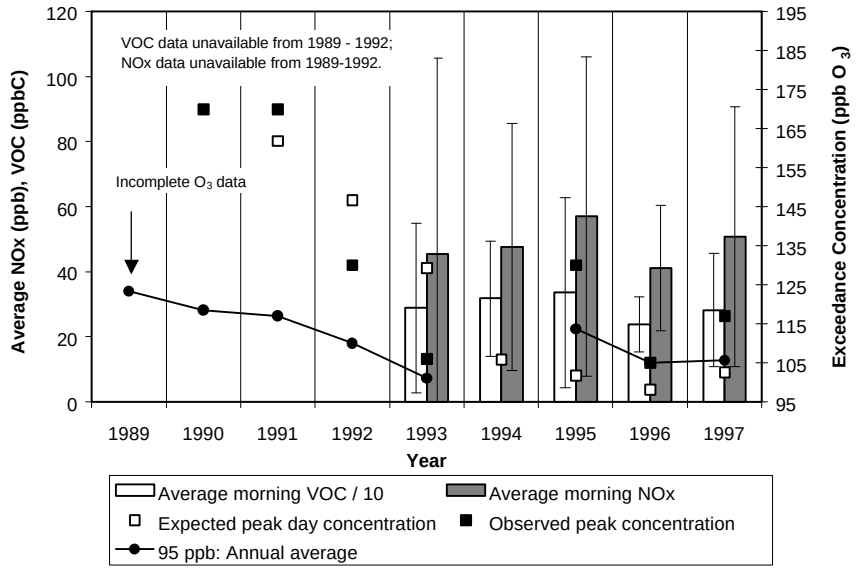


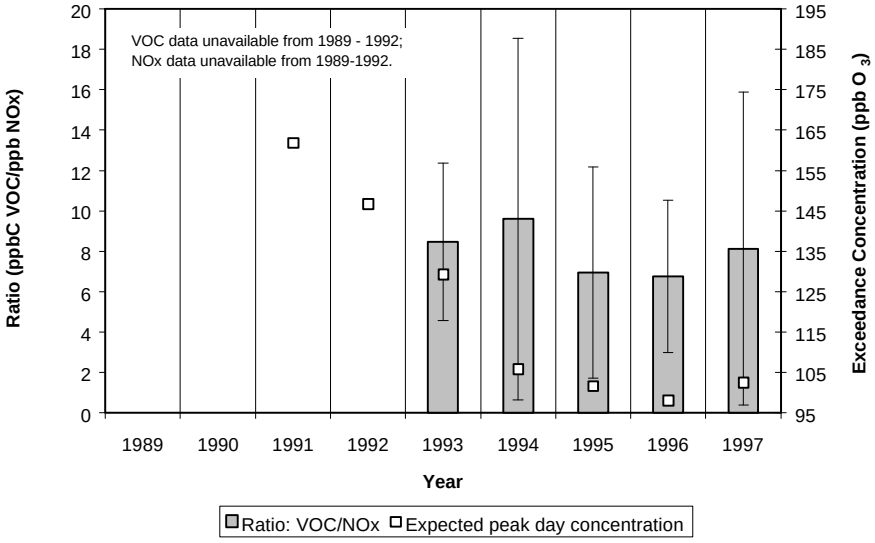
12th Street - Number and fraction of the exceedances of the California Ozone Standard by meteorology.





12th Street - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentrations.





APPENDIX G

ADDITIONAL VENTURA ANALYSES

Statistical techniques were applied to three Ventura PAMS sites: Emma Wood Beach (PAMS Type 1 site), El Rio (PAMS Type 2 site), and Simi Valley (PAMS Type 3 site). The analyses considered exceedances of both the California Ozone Standard and the 1-hour Ozone NAAQS. However, only exceedances of the 1-hour Ozone NAAQS experienced at the Simi Valley site were detailed in Section 9 of the report. The following figures are presented in this Appendix and parallel the analyses of the Simi Valley site data and the 1-hr Ozone NAAQS that was presented in Section 9:

- Simi Valley - Exceedances of the California Ozone Standard with analysis uncertainty.
- Simi Valley - Total number of exceedances of the California Ozone Standard.
- Simi Valley - Identification of the highest exceedance concentrations of the California Ozone Standard.
- El Rio - Exceedance concentrations of the California Ozone Standard as a function of early morning precursor concentration.

The following figures are presented in this Appendix and pertain to additional analyses of ozone trends that were performed for the Emma Wood Beach and El Rio sites. The figures for each site are presented separately in the following order:

- Exceedances of the California Ozone Standard with analysis uncertainty.
- Total number of exceedances of the California Ozone Standard.
- Identification of the highest exceedance concentrations of the California Ozone Standard.
- Exceedances of the 1-hr Ozone NAAQS with analysis uncertainty.
- Total number of exceedances of the 1-hr Ozone NAAQS.
- Identification of the highest exceedance concentrations of the 1-hr Ozone NAAQS.

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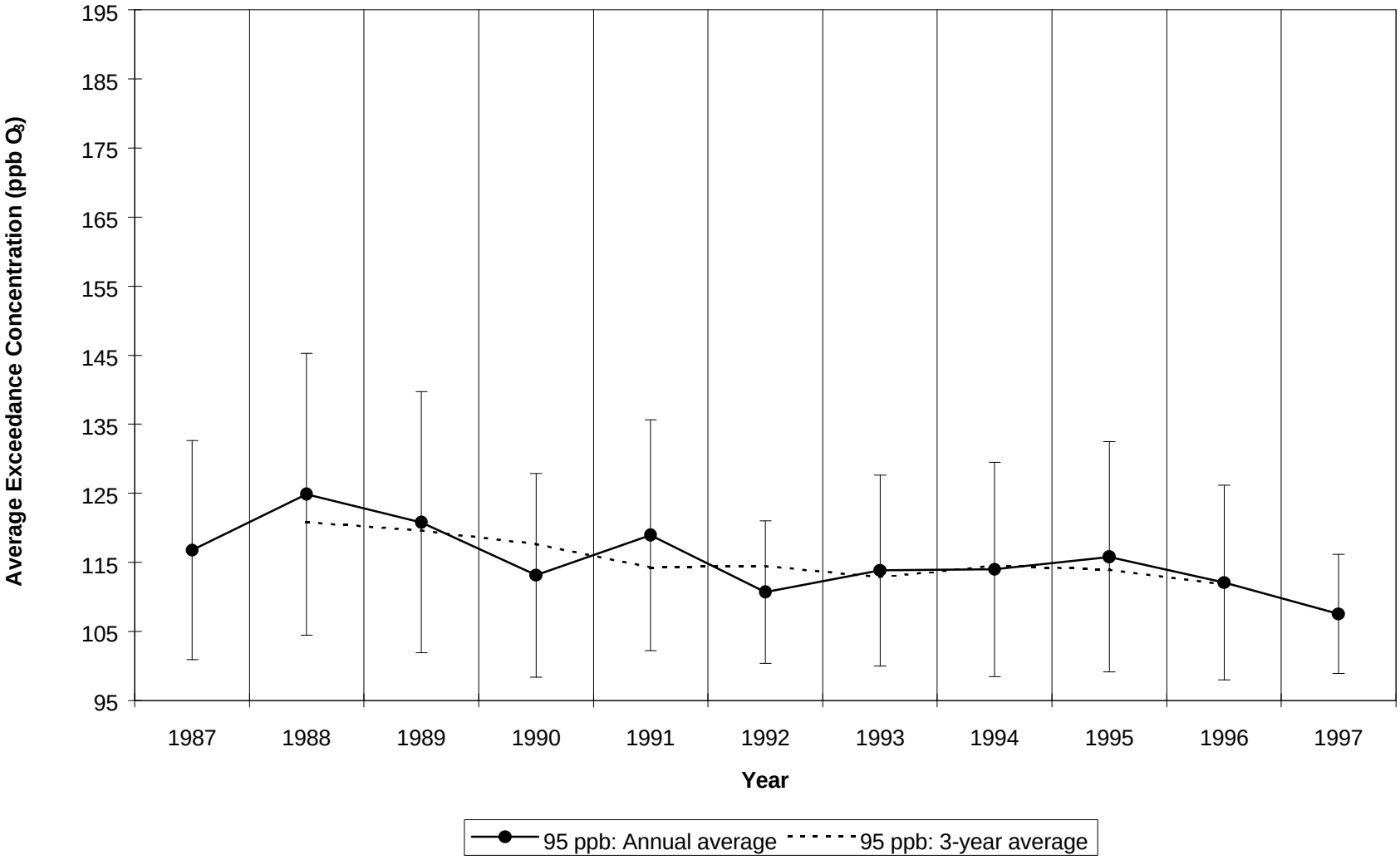
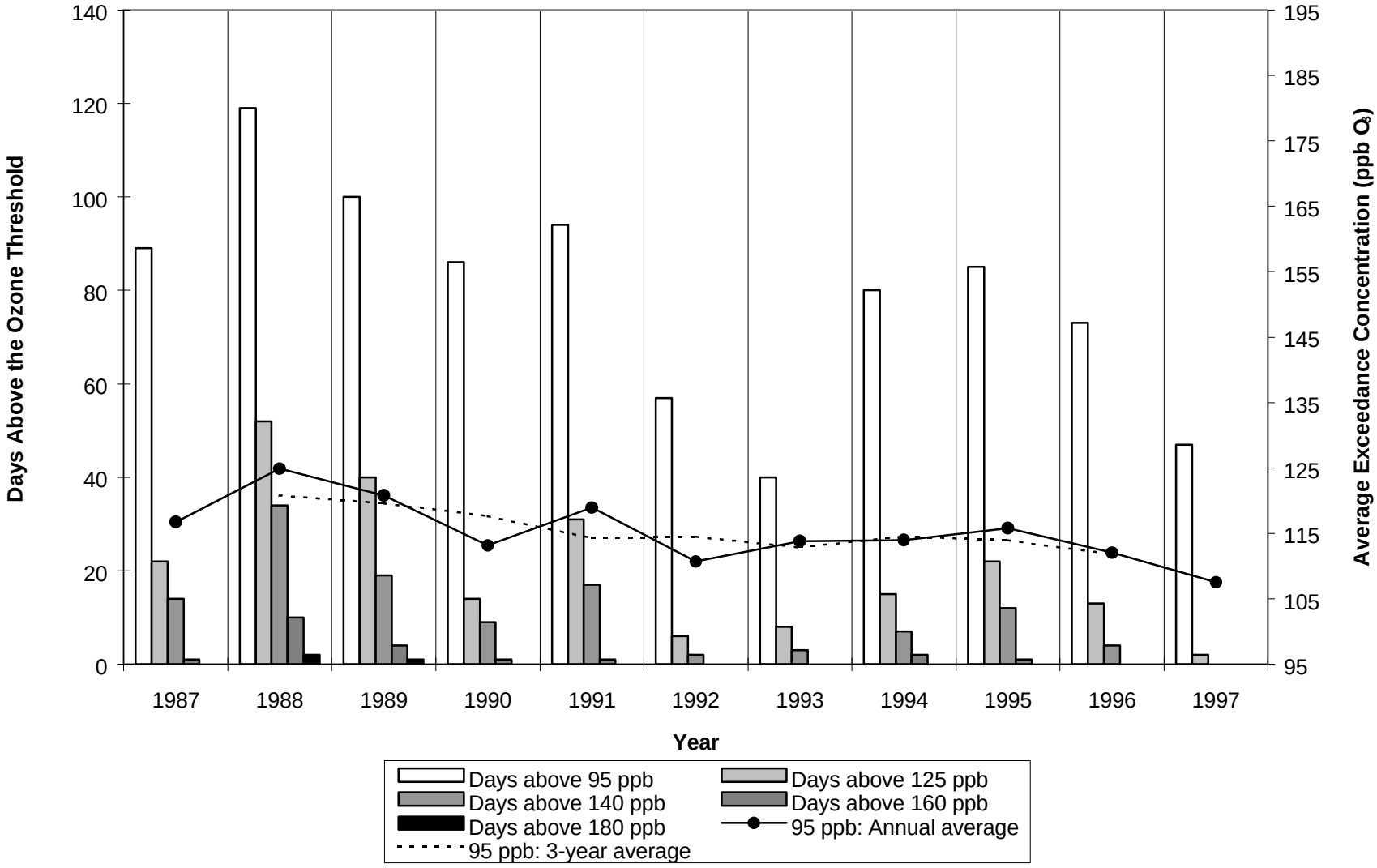
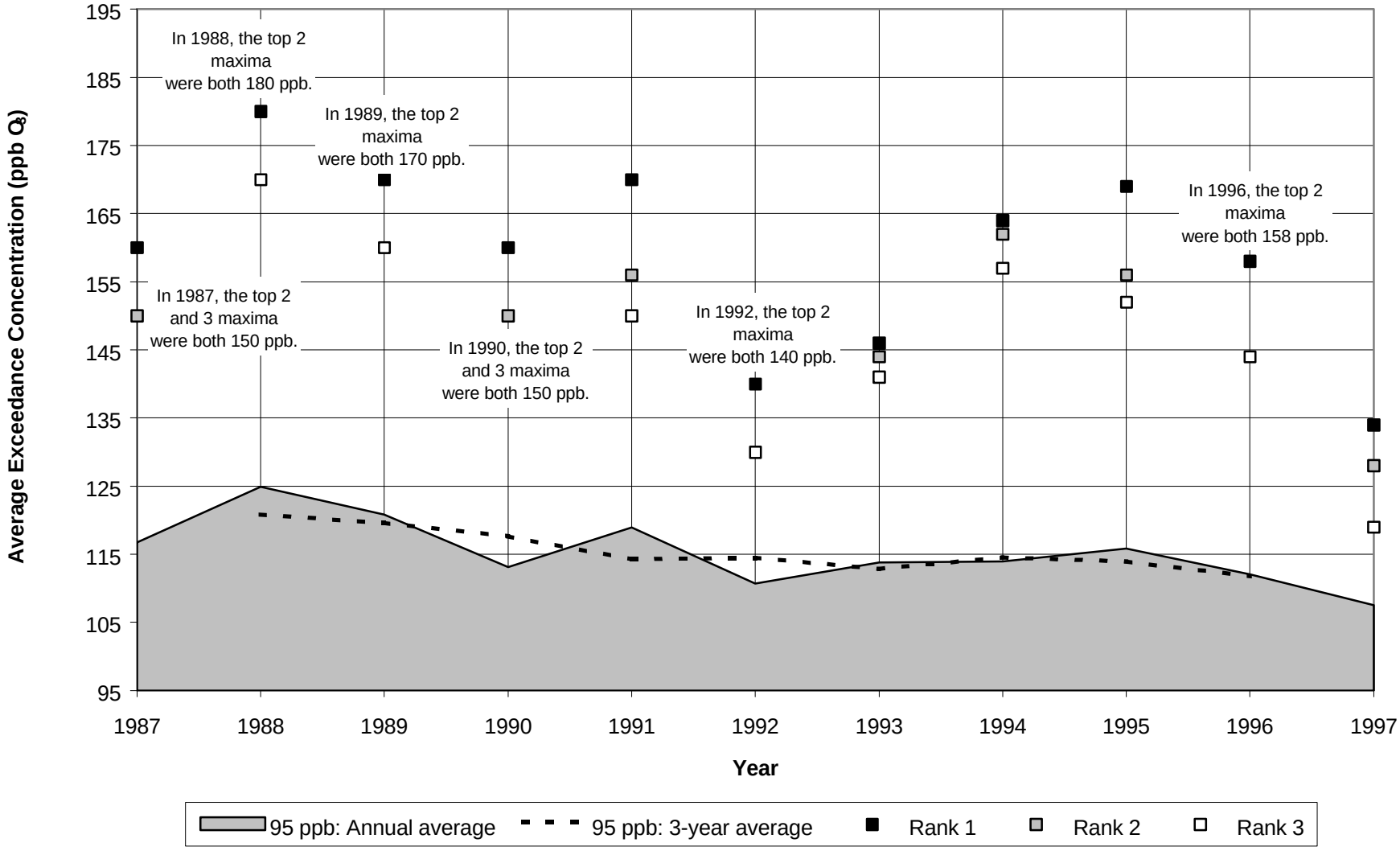
Simi Valley - Exceedances of the California Ozone Standard with analysis uncertainty.



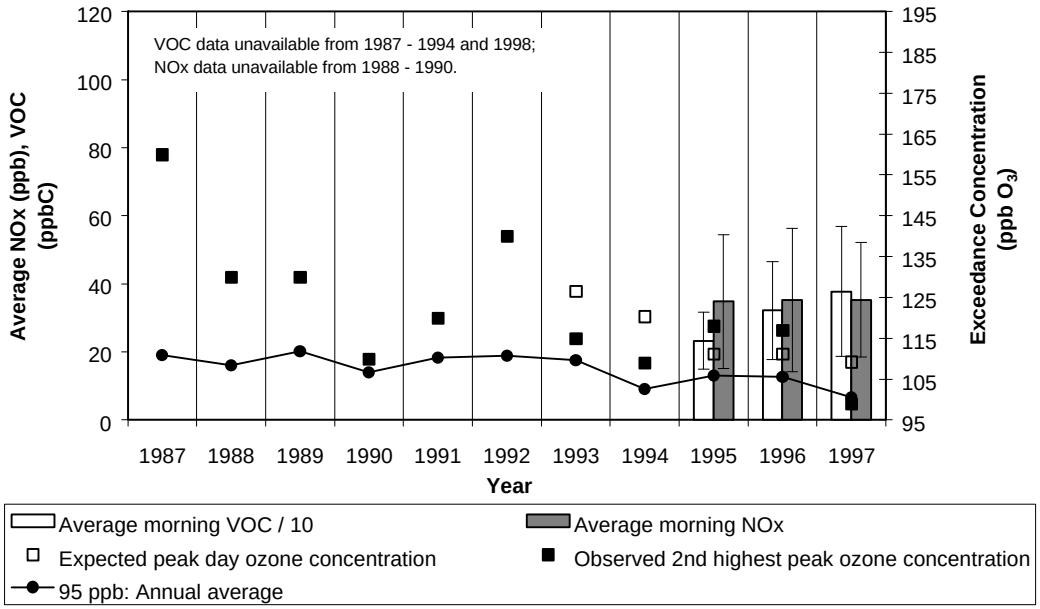
Simi Valley - Total number of exceedances of the California Ozone Standard.

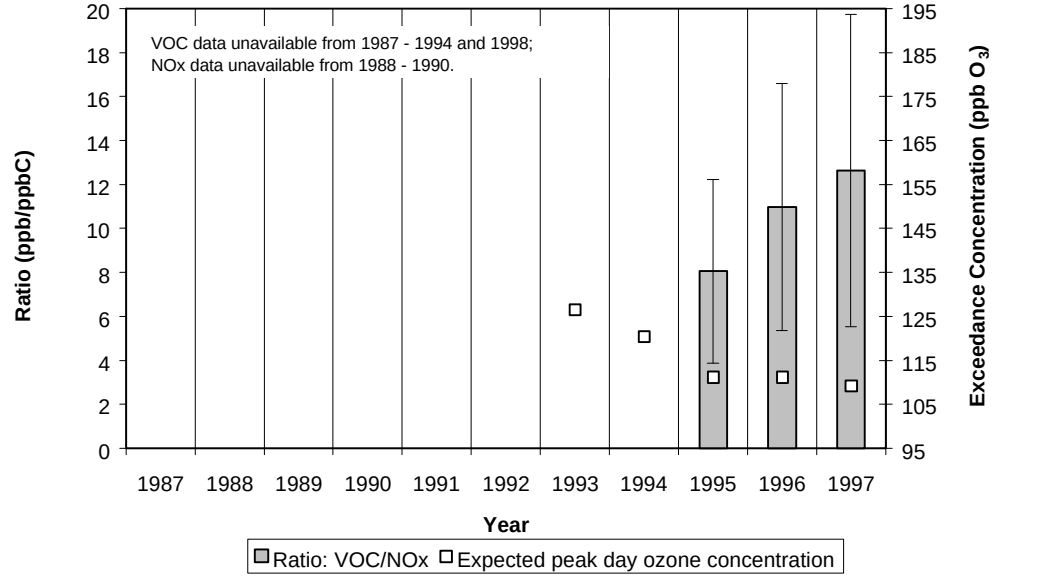


Simi Valley - Identification of the highest exceedance concentrations of the California Ozone Standard.

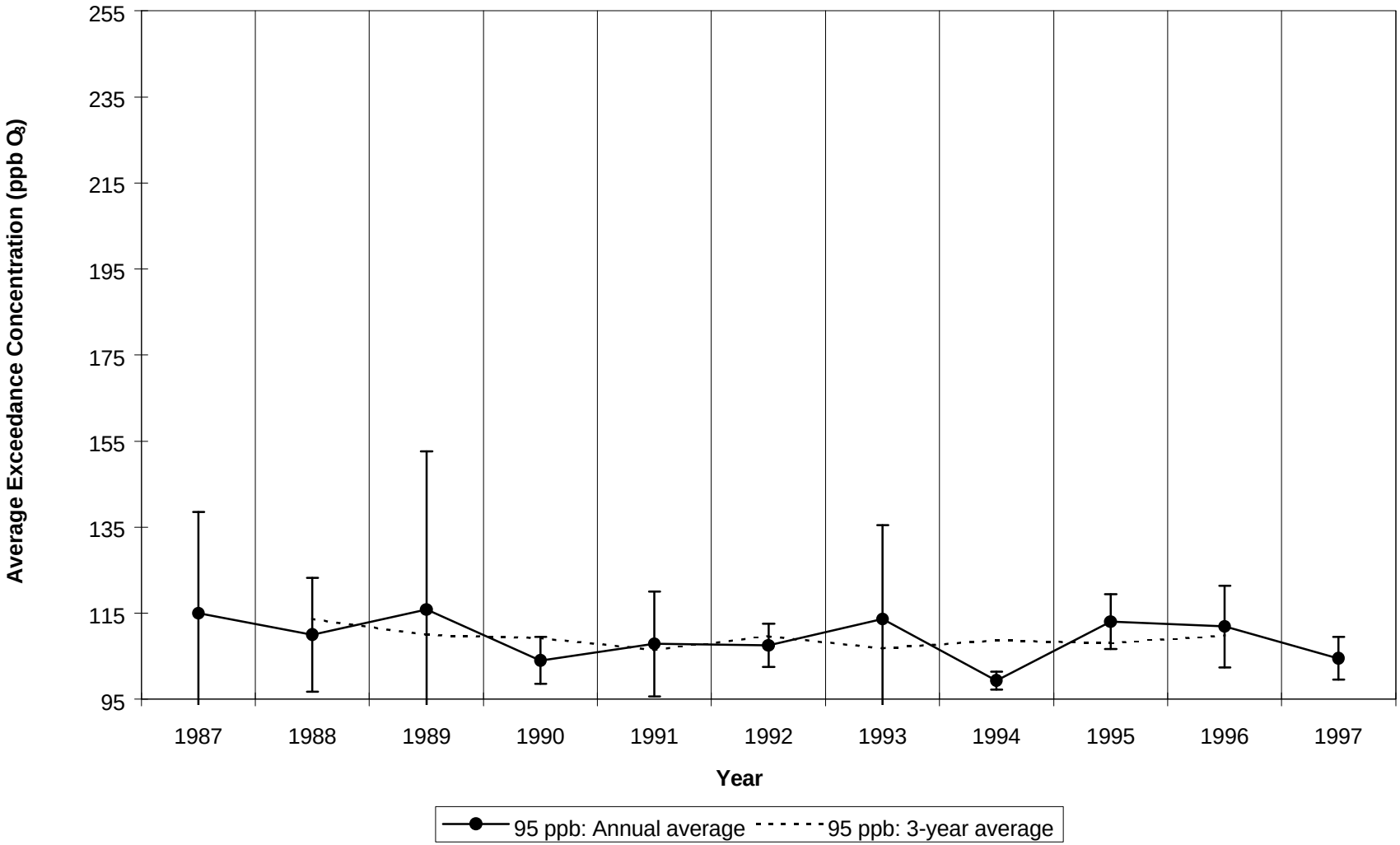


El Rio - Exceedance concentrations of the California Ozone Standard
as a function of early morning precursor concentrations.

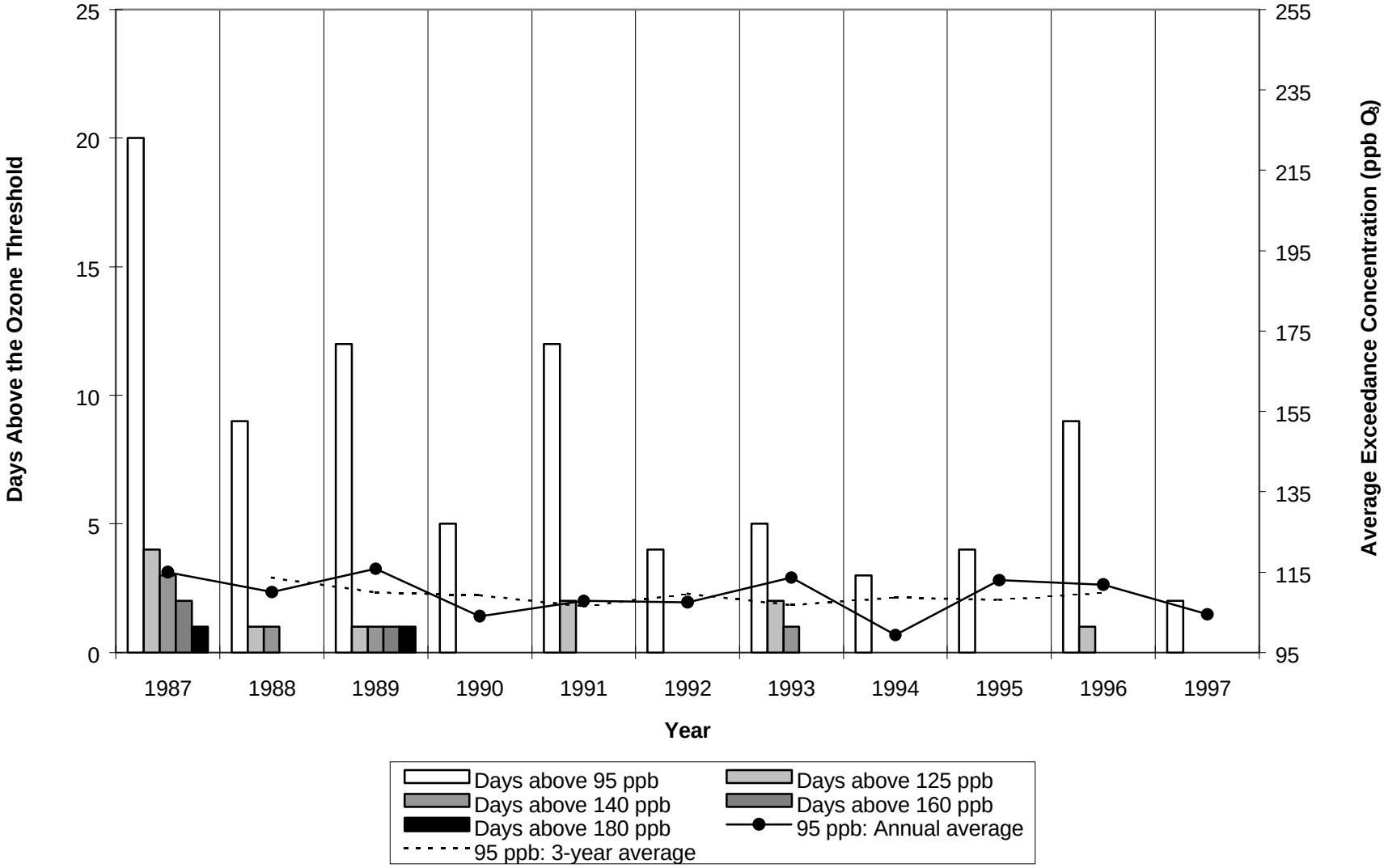




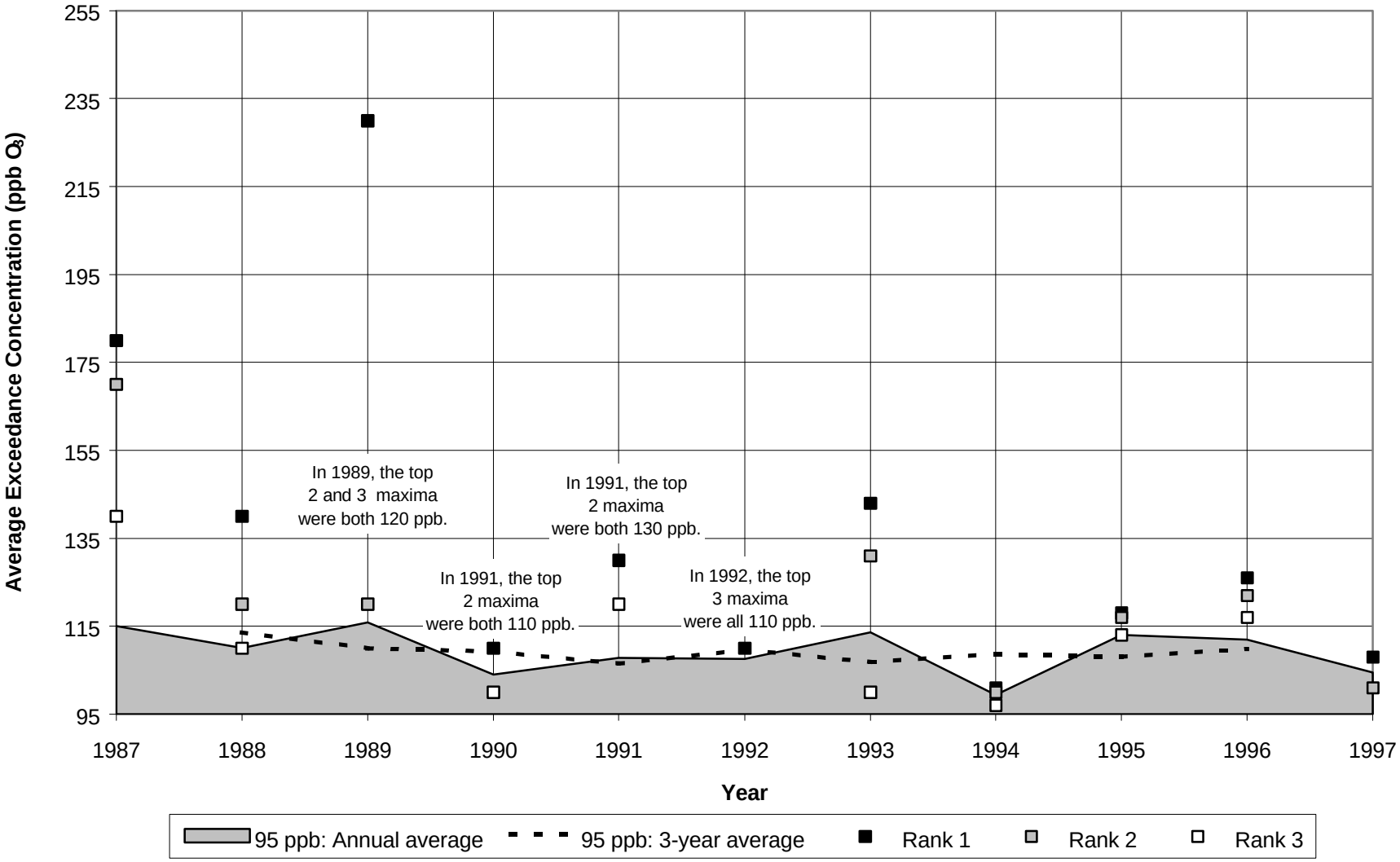
Emma Wood Beach - Exceedances of the California Ozone Standard with analysis uncertainty.



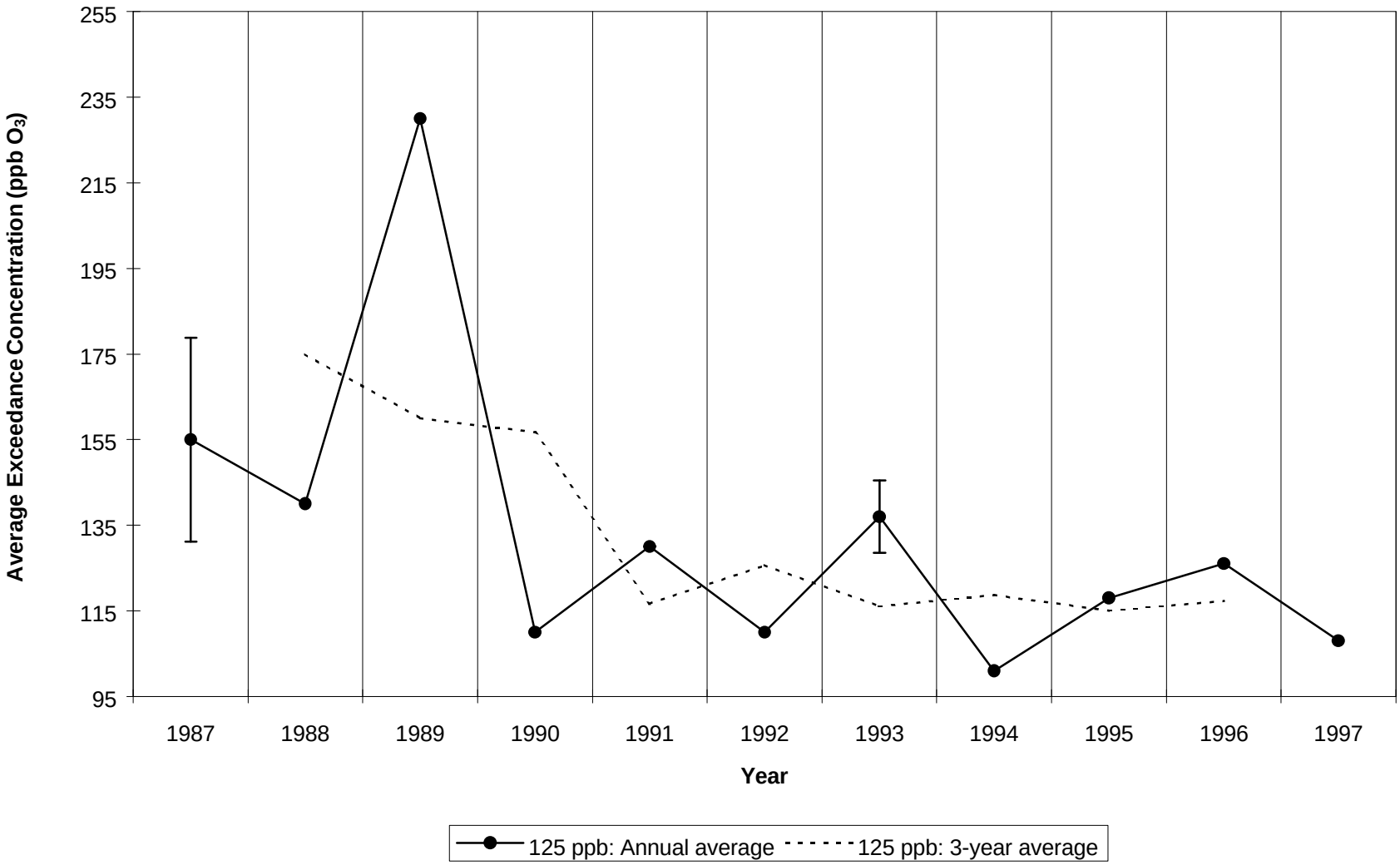
Emma Wood Beach - Total number of exceedances of the California Ozone Standard.



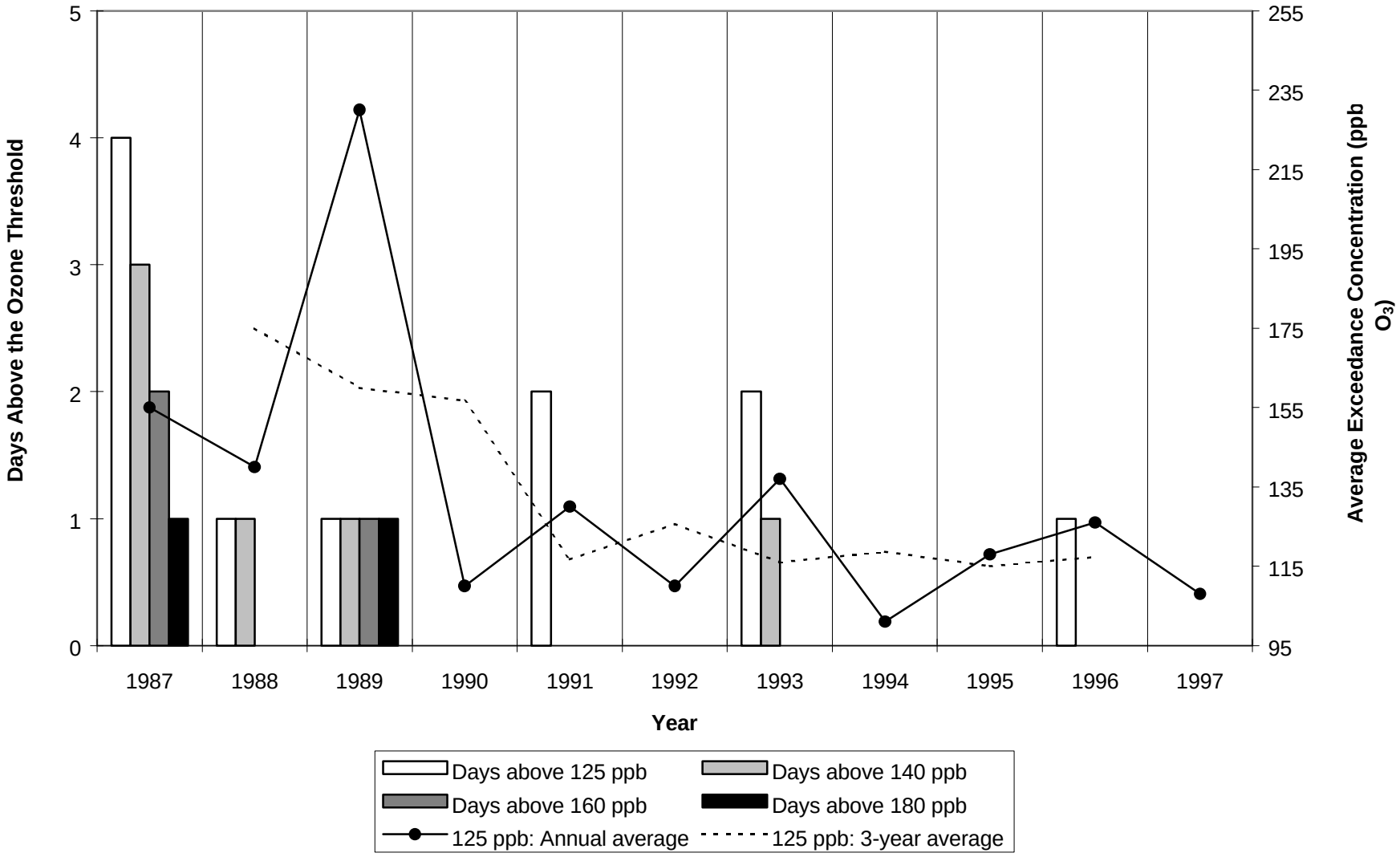
Emma Wood Beach - Identification of the highest exceedance concentrations of the California Ozone Standard.



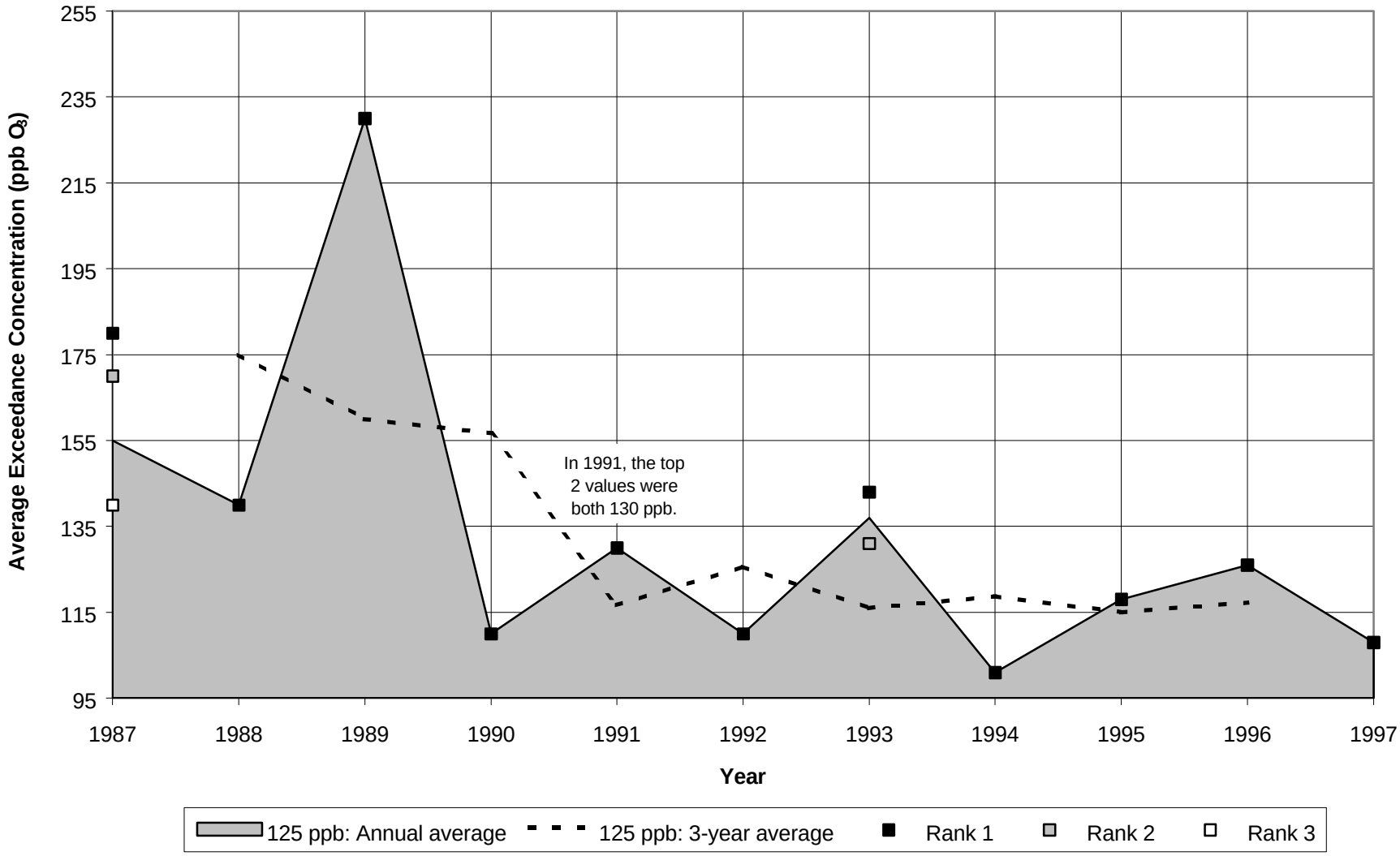
Emma Wood Beach - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty.



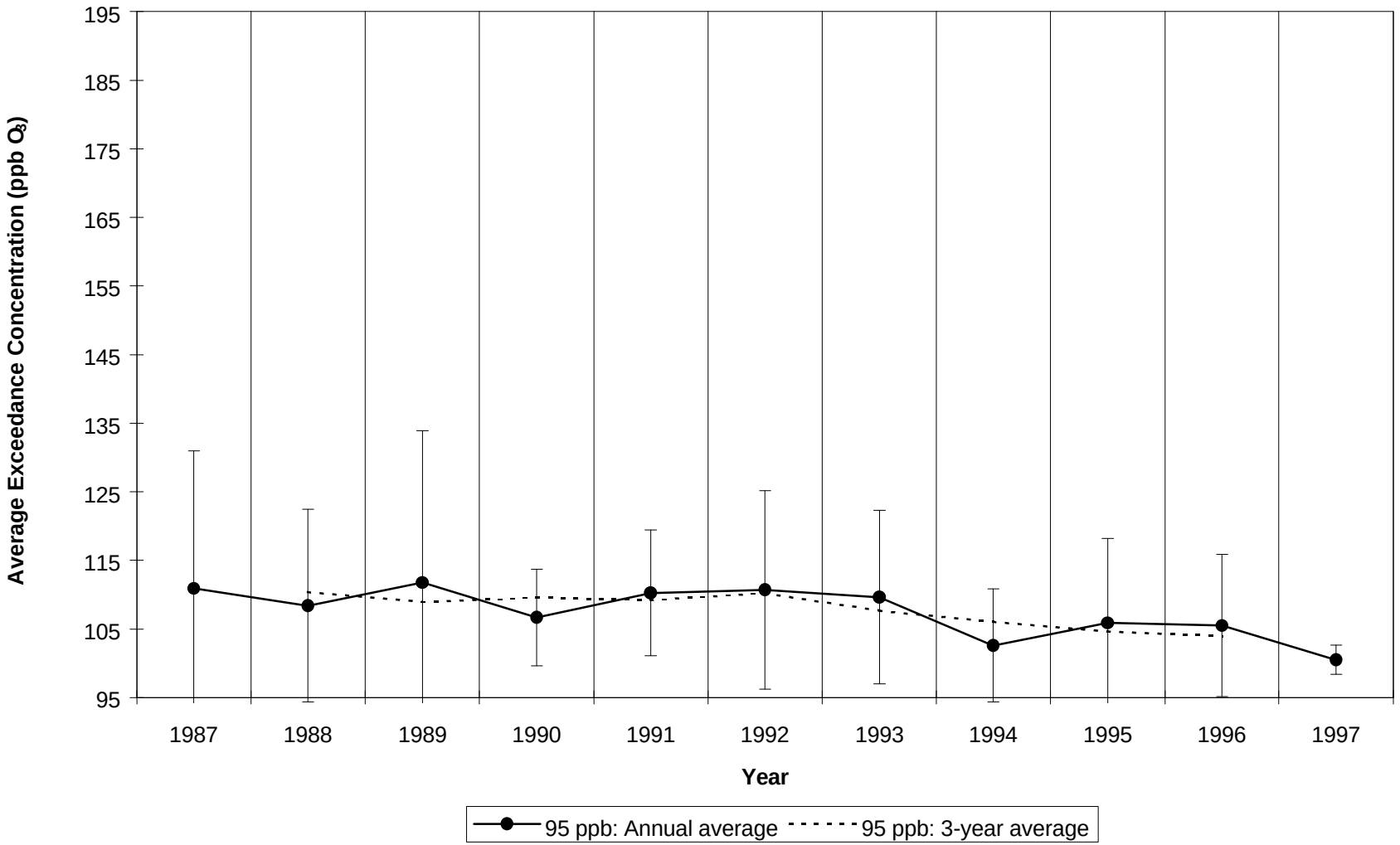
Emma Wood Beach - Total number of exceedances of the 1-hour Ozone NAAQS.



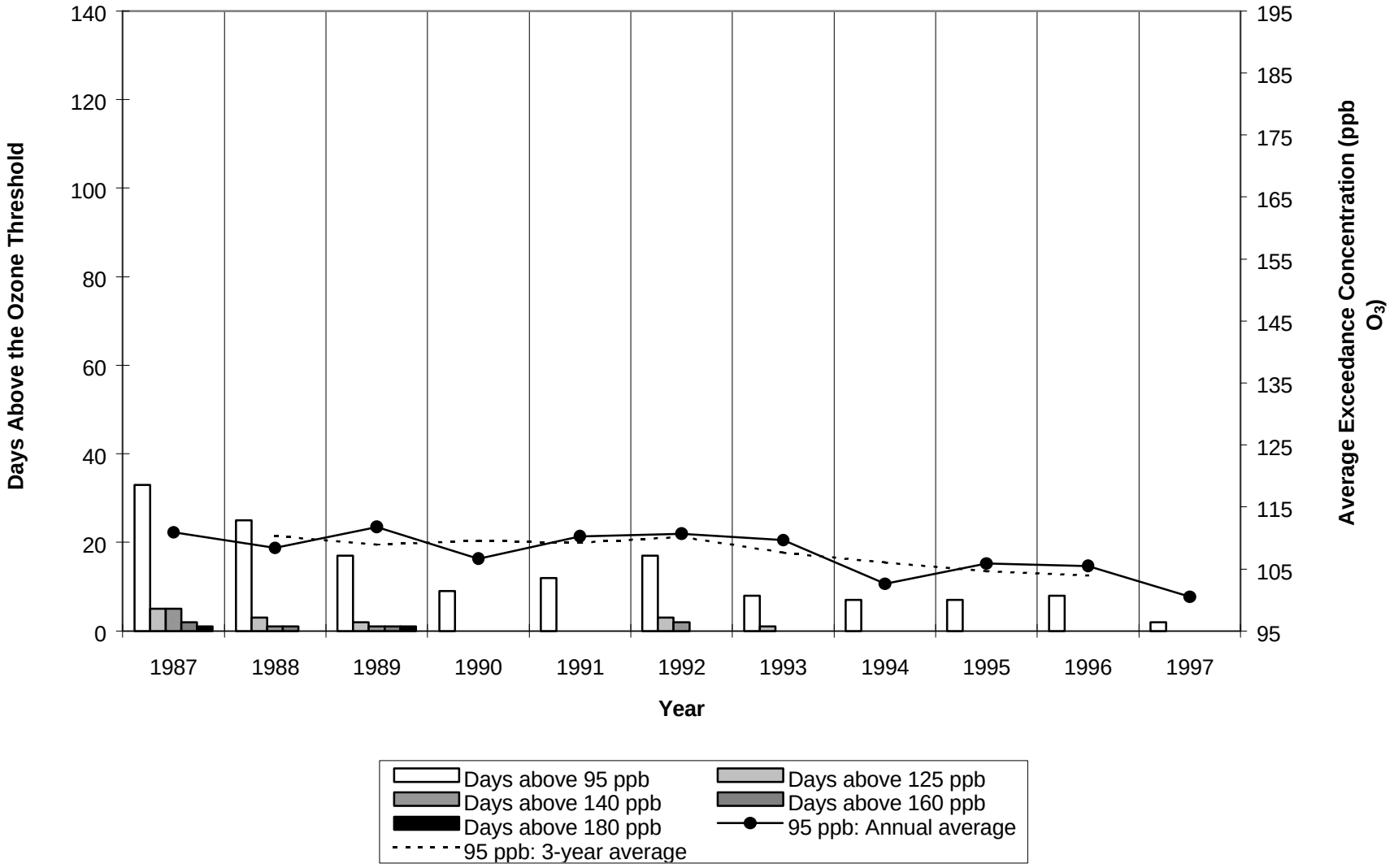
Emma Wood Beach - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.



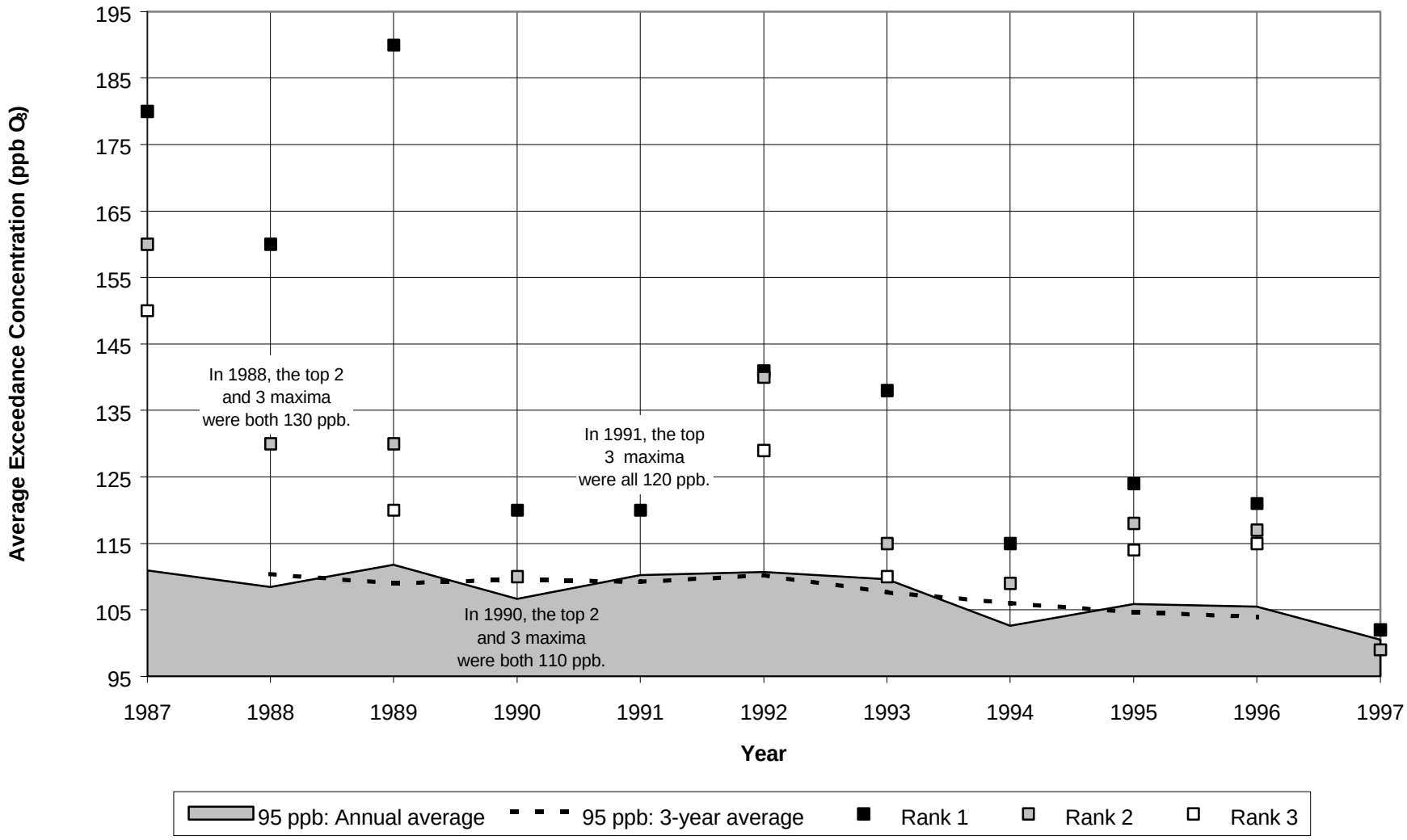
El Rio - Exceedances of the California Ozone Standard with analysis uncertainty.



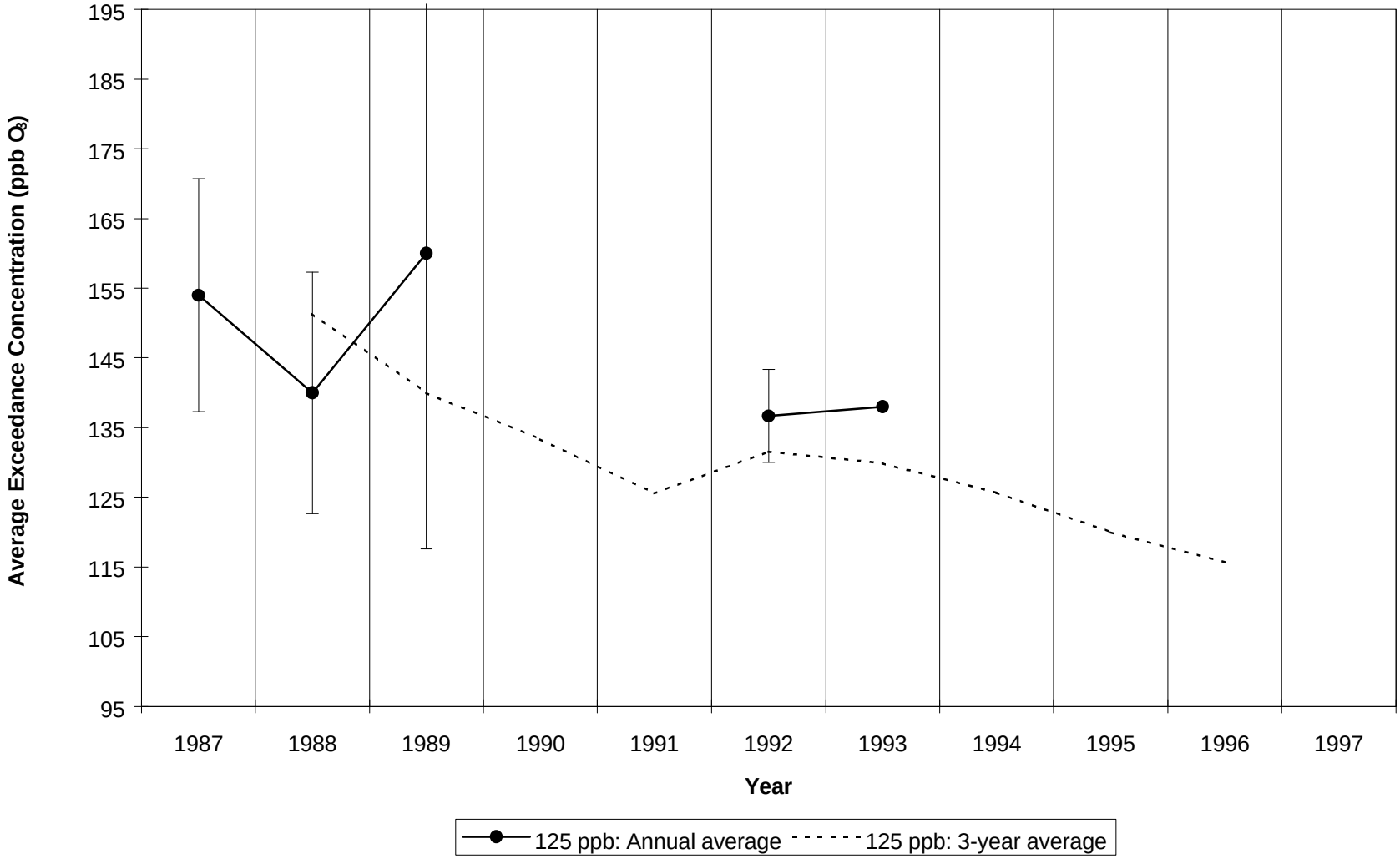
El Rio - Total number of exceedances of the California Ozone Standard.

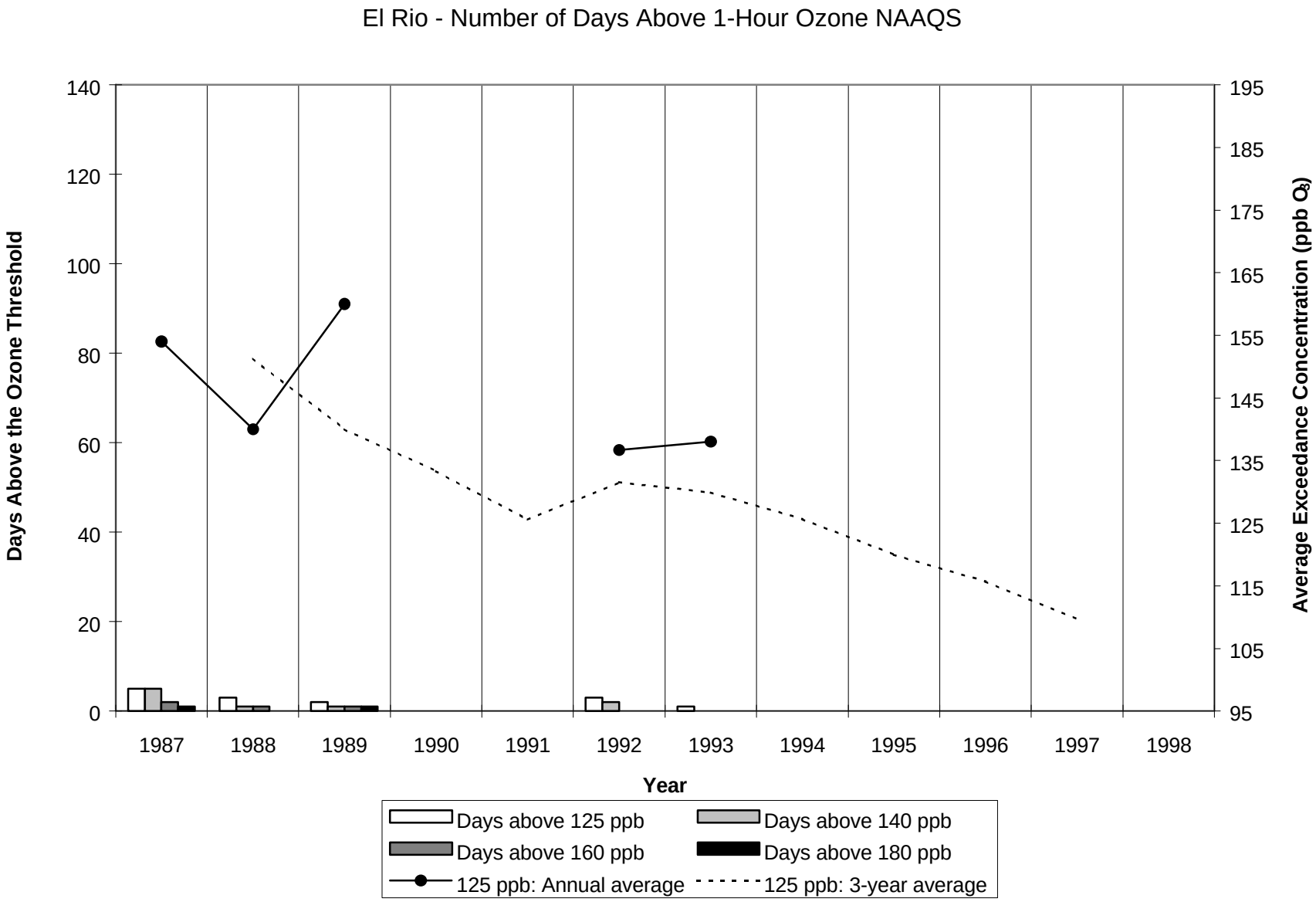


El Rio - Identification of the highest exceedance concentrations of the California Ozone Standard.



El Rio - Exceedances of the 1-hour Ozone NAAQS with analysis uncertainty.




El Rio - Number of Days Above 1-Hour Ozone NAAQS
Days Above the Ozone Threshold
Average Exceedance Concentration (ppb O3)
140
120
100
80
60
40
20
0
195
185
175
165
155
145
135
125
115
105
95
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
Days above 125 ppb
Days above 140 ppb
Days above 160 ppb
Days above 180 ppb
125 ppb: Annual average
125 ppb: 3-year average

El Rio - Identification of the highest exceedance concentrations of the 1-hour Ozone NAAQS.